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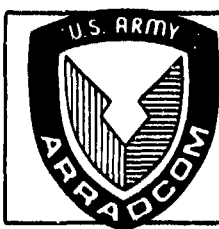
**COMPUTER SIMULATION OF ARTILLERY S&A MECHANISM
(INVOLUTE GEAR TRAIN AND STRAIGHT-SIDED VERGE
RUNAWAY ESCAPEMENT)**

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**US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER
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DOVER, NEW JERSEY**

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20. ABSTRACT (cont)

it makes it possible to determine the maximum value of the contact forces in the gear train as well as in the escapement. A simulation run with the dimensions of the M739 safing and arming mechanism showed excellent agreement with experimental results when a system coefficient of friction of 0.1 was used.

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INTRODUCTION

A computer simulation was developed for a complete artillery safing and arming (S&A) mechanism containing a straight-sided verge runaway escapement. Figures 1 and 2 show the essentials of two different configurations of such a mechanism which, in addition to the escapement, contains a spin driven rotor and a two-pass involute gear train.

While the mathematical model of the verge runaway escapement represents a new study, the description of the rotor and the gear train, together with the essence of the computer program, is based to a considerable extent on reference 1, which deals with the computer simulation of an S&A mechanism containing a pin pallet runaway escapement.

As in reference 1, the three motion regimes of the runaway escapement (coupled motion, free motion, and impact) are considered. Again, the pallet of the escapement may have an arbitrarily-located center of mass.

Complete derivations are given for the mathematical model, including the configuration variations. A detailed description and operational instructions are given for the associated computer program whose output furnishes instantaneous kinematic conditions of the escapement components and the number of turns to arm, as well as all non-impact contact forces. This program was extensively tested for the configuration no. 2 data (fig. 2) of the M739 fuze S&A mechanism. This mechanism simulation required approximately 26 turns to arm when a system coefficient of friction of 0.1 was used.

DESCRIPTION OF COMPUTER PROGRAM

The following gives the essential steps of program SANDA2V which is listed in appendix A. The mathematical model of the verge runaway escapement naturally differs from that of the pin pallet escapement as shown in reference 1, especially since the differential equations for entrance- and exit-coupled motions in the verge escapement are not the same. However, the programming schemes are essentially identical. Thus, with the exception of controls pertaining to the aforementioned entrance- and exit-coupled motions, the program runs parallel to the one associated with the pin pallet escapement.

The following outlines the essential features of the program without giving specific control details.

The main program starts with reading in and writing of all relevant physical data. This is followed by the computation of gear ratios, fuze body angles, centrifugal forces, gear train constants, and earliest and latest possible values of the gear angles by way of subroutine ALFA, as well as the initialization of the gear angles. The simulation begins with the entrance-coupled motion at a starting angle PHID, which represents that angle ϕ of the escape wheel which is associated with the approximate center of the entrance working surface of the

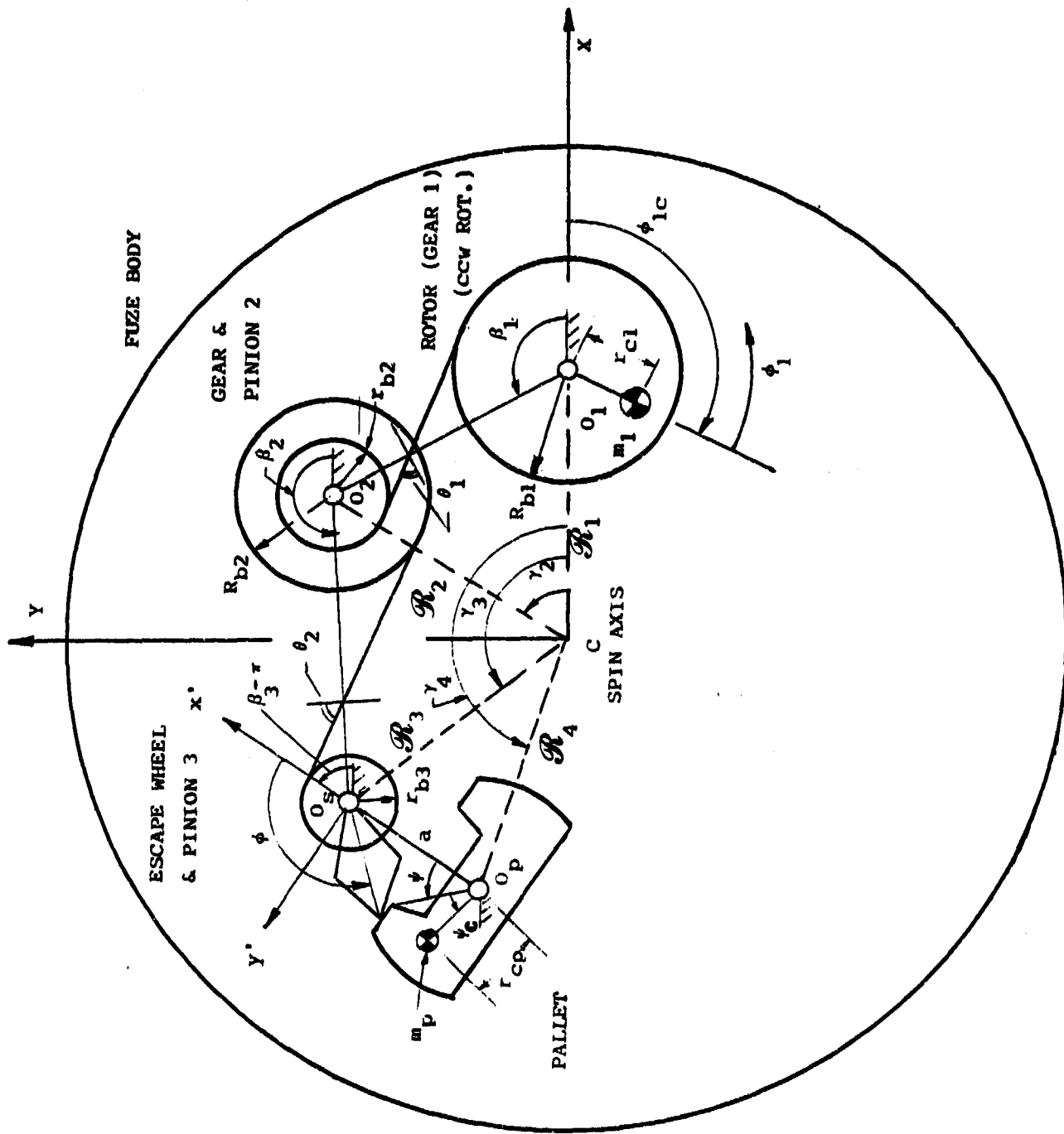


Figure 1. Rotor driven S&A device, configuration no. 1

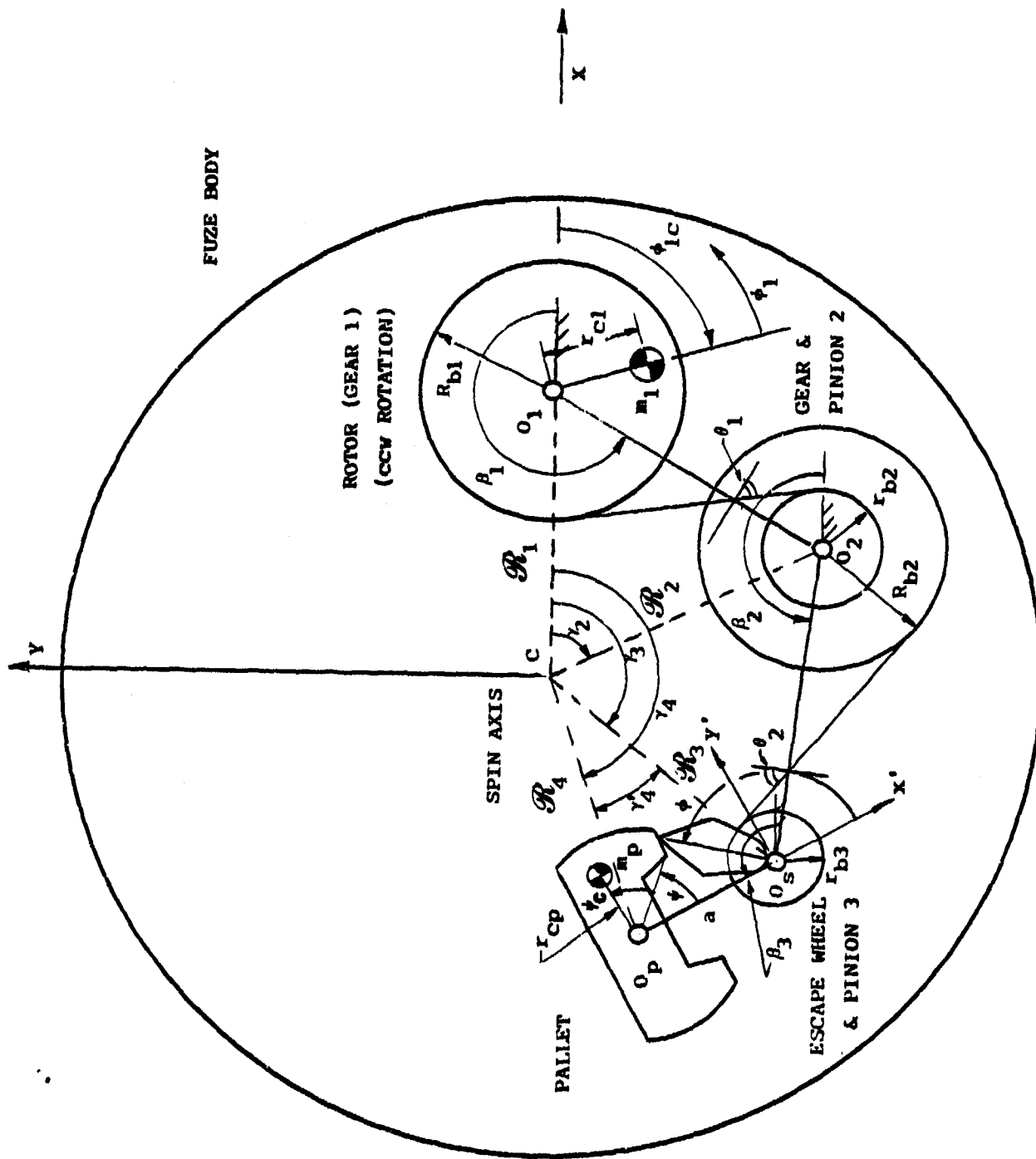


Figure 2. Rotor driven S&A device, configuration no. 2

pallet. This angle then corresponds to a cumulative escape wheel angle PHITOT of 0°.

Coupled Motion (Location 1)

Depending on whether entrance- or exit-coupled motion takes place, differential equation B-100 or equation B-119 of appendix B must be solved. To this end, the main program calls on an available fourth-order Runge-Kutta routine.¹ The main purpose of the subroutine FCT is to present the second-order differential equation in terms of two first-order ones to RKGS. PHI(1) and PHI(2) represent the angle ϕ and the angular velocity $\dot{\phi}$, respectively. The computation of all parameters of the differential equation takes place in subroutine FCT as well as in subroutines IN2 and KINEM.

The subroutine KINEM computes current values of g , ψ and $\dot{\psi}$, as shown in appendix C, as well as of the moment arms A_1^i , B_1^i , C_1^i , and D_1^i as shown in appendix D.

Subroutine IN2 computes various gear mesh parameters and instantaneous mesh contact angles, as well as the signum functions s_1 , s_2 , s_4 , and s_5 . In addition, the parameters A_1 to A_{44} , listed in appendix B, are obtained. It is to be noted that the parameters A_1 , A_5 , A_9 , A_{12} , A_{17} , and A_{18} depend on whether entrance- or exit-coupled motion is involved.² The parameters A_{45} to A_{50} are computed in subroutine FCT. The reason for this division is found in the limited number of arguments permitted in any one subroutine. Finally, the gear-indexing operation, as outlined in reference 2, is performed with the help of the angle ϕ .

The following discusses the manner in which the instantaneous rotor angle $\phi_{1C} + N_{31}\phi_T$ of the coupled motion differential equations must be expressed in subroutine FCT. Recall that ϕ_{1C} is the initial rotor angle, ϕ_T is the total angle of rotation of the escape wheel, and N_{31} stands for the gear ratio between the rotor and the escape wheel. Since the angle ϕ with the Runge-Kutta variable PHI(1) varies between approximately 134° and 144° during entrance- and between 209° and 216° during exit-coupled motion, the total escape wheel angle ϕ_T can only be obtained by continuously adding the increments due to each cycle of Runge-Kutta computations. Thus,

$$\phi_T = \phi_{TOT} + \Delta\phi \quad (1)$$

¹ RKGS Routine, IBM System/360 Scientific Subroutine Package (360A-CM-0X3), Version III.

² The program uses the symbols AA1, etc. throughout. This should not be confused with the symbols AA₁ to AA₁₈, which are used in the combined exit-coupled motion differential equation (B-119).

where

ϕ_{TOT} = total escape wheel angle up to a certain Runge-Kutta cycle.
(This is represented by PHITOT in the program.)

$\Delta\phi$ = increment of escape wheel during this Runge-Kutta cycle.

The increment $\Delta\phi$ is calculated as the difference between the latest value of PHI(1) and its previous one which has been stored as PHIPR. In this manner, equation 1 becomes

$$\phi_T = PHITOT + PHI(1) - PHIPR \quad (2)$$

Subroutine FCT also decides on the values of I_{PR} and I_{IR} as required by equations B73 and B74 as well as equations B150 and B151 (app B). The associated conditional statements assign the larger values for these combined moments of inertia whenever the product of the angular velocity and the angular acceleration is positive; i.e., both quantities have the same sign.

The associated subroutine OUTP is responsible for printing out the results ϕ , $\dot{\phi}$, and $\ddot{\phi}$, together with the current values of time, g, ψ , $\dot{\psi}$, and PHITOT. Further, all coupled motion contact forces are calculated according to equations B183 and B186, and the maximum values of these forces during one-rotor cycle are determined.

Free Motion (Location 5)

The differential equations of free motion, as given by equation B187 for the pallet and equation B193 for the combined escape wheel, gear train, and rotor are again solved by the Runge-Kutta routine. To obtain the magnitudes of the variables ϕ and ψ , as well as their derivatives at identical times, the two independent second-order differential equations are transformed into four simultaneous first-order ones. (While only the two first-order equations associated with each of the two variables are actually coupled, the routine treats all four as if they were coupled and thus produces solutions for identical time increments.) These four expressions, which are presented in subroutine FCTF, are of the following form:

$$DX(1) = X(2) : (= \dot{\phi}) \quad (3)$$

$$DX(3) = X(4) : (= \dot{\psi}) \quad (4)$$

$$DX(2) = \frac{1}{A_{55}} [-A_{56}(X(2))^2 + A_{57}X(2) + A_{58} + A_{59}\sin(\phi_{1C} + N_{31}(\phi_T + X(1) - PHIPR))] : (= \ddot{\phi}) \quad (5)$$

$$DX(4) = \frac{1}{A_{51}} [-A_{21} (X(4))^2 - A_{52}X(4) - A_{53} + A_{54}\sin(\gamma_p' - \psi - \psi_c)] : (\ddot{\psi}) \quad (6)$$

The subroutine FCTF also computes the parameters A_{51} to A_{59} and calls on subroutine IN2 for the computation of all gear-related parameters.³

The associated subroutine OUTPF computes the free motion contact forces according to equations B199 and B200 and finds their maxima after determining the parameters A_{51} to A_{59} . The computation of these latter variables also requires a call on subroutine IN2. In addition to the above, a continuous count of PHITOT is provided in OUTPF. This angle, time, ϕ , $\dot{\phi}$, ψ , $\dot{\psi}$, and the contact forces are printed out. This subroutine also makes the decision whether or not to remain in free motion. The sensing variables f and $g' = GP$ (equations E4 and E5 of appendix E) are used for this purpose.

Impact (Location 15)

The subroutine IMPACT uses the current values of the angular velocities $\dot{\phi}_1$ and $\dot{\psi}_1$ and computes the post impact angular velocities $\dot{\phi}_f$ and $\dot{\psi}_f$, applying equations B211 and B212 of appendix B. (Note that the moment of inertia of the escape wheel is now expressed according to equation B213 (app B), which refers the rotor as well as the gear train inertias to the escape wheel.)

Reversal of Gear Train Motion Due to Impact

If the impact torque on the escape wheel is sufficiently large, the motion of the gear train may be temporarily reversed; i.e., the escape wheel angular velocity $\dot{\phi}$ may become negative. This would cause the friction forces between the gear teeth and at the various gear pivots to be reversed in direction. (The normal forces between the gear teeth remain unaffected, and the normal bearing forces are obtained in the usual manner.) This change in the direction of the friction forces is expressed for both coupled and free motion by letting the coefficient of friction μ of all gear train components become negative (discussed in app E of ref 1). This is accomplished in subroutine IN2 by the following use of the signum function $\dot{\phi}/|\dot{\phi}|$:

$$MU = ABS(MU) * \dot{\phi}/|\dot{\phi}| \quad (7)$$

³ Whenever $A_{51} = I_{PR} = 0$, the simulation stops because of the division by zero. Should this occur, FCTF prints "IPR EQUALS ZERO - SIMULATION TERMINATED."

(The coefficient of friction associated with the escapement interface and the pallet pivot is called μ_1 and is read into the program as MU1.) Any motion reversal at these surfaces is accounted for by the signum functions s_4 and s_5 , respectively.

Termination of Computations

Computations are terminated whenever the geared motion of the rotor ends. This corresponds to $\uparrow = \text{PHICUTD}$. The duration of the subsequent unretarded motion of the rotor is assumed to be negligible.

COMPUTER SIMULATION OF EXAMPLE MECHANISM

This section discusses a computer simulation of a modified S&A device of the M739 fuze. The mechanism has configuration no. 2, as shown in figure 2, and contains a newly-designed involute gear train. While this gear train has the same gear ratio and individual center distances as the original design, each of the meshes now has unity contact ratio.⁴ The simulation of this mechanism was accomplished with the help of computer program SANDA2V which, with a sample output, is listed in appendix A. It was run for 30,000 rpm to obtain maximum contact forces.

The following shows the input requirements of the program, explains the various output data, and discusses the manner in which the "number-of-turns-to-arm" is obtained for a given spin velocity.

Input Data (Appendix A)

The first portion of the output repeats all input data, which represent the mechanism parameters of the M739 fuze. These are listed both as computer variables and as symbols, according to appendixes C and F of this report:

⁴ Both meshes were designed with the help of computer programs INVOL11 and GEARPARAM2, originally shown in Progress Report No. 11 of the "Development of Automated Design Optimization Technique for Safety and Arming Devices" (Contract No. DAAK10-79-C-0251, January 15, 1981). Copies of this report may be obtained from either F. R. Tepper, ARRADCOM or G. G. Lowen, The City College of New York.

Escapement Parameters

$A = a = 0.226$ in. (5.740 mm) = distance between pivots O_p and O_s
(fig. 2)

$B = b = 0.168$ in. (4.267 mm) = escape wheel radius

$C = c = 0.13138$ in. (3.337 mm) = pallet radius as defined by figure
F-1 of appendix F

ALPHEN = $\alpha_{en} = 43.5352^\circ$ = entrance working surface angle

ALPHEX = $\alpha_{ex} = 29.2981^\circ$ = exit working surface angle

NT = 4 = number of escape wheel teeth spanned by verge

CONFIG = 2 = Configuration no. 2 (See section on fuze body configuration
no. 2 in appendix B.)

EREST = $e_r = 0$ = Coefficient of restitution

LAMBDA = $\lambda = 92.93^\circ$ = angle between entrance and exit pallet radii
(figure F-1 in appendix F)

N = 22 = Number of escape wheel teeth

For details of the above nomenclature, see appendixes C, E, and F.

Mass Parameters of Components

M1 = $m_1 = 0.3165 \times 10^{-4}$ lb-sec²/in. (5.552×10^{-3} kg) = mass of rotor

M2 = $m_2 = 0.3275 \times 10^{-5}$ lb-sec²/in. (5.745×10^{-4} kg) = mass of gear and
pinion no. 2

M3 = $m_3 = 0.2631 \times 10^{-5}$ lb-sec²/in. (4.615×10^{-4} kg) = mass of escape
wheel and pinion no. 3

MP = $m_p = 0.1640 \times 10^{-5}$ lb-sec²/in. (2.877×10^{-4} kg) = mass of pallet

I1 = $I_1 = 0.1967 \times 10^{-5}$ in.-lb-sec² (2.226×10^{-7} kg-m²) = moment of
inertia of rotor

I2 = $I_2 = 0.4026 \times 10^{-7}$ in.-lb-sec² (4.556×10^{-9} kg-m²) = moment of
inertia of gear and pinion no. 2

I3 = $I_3 = 0.2125 \times 10^{-7}$ in.-lb-sec² (2.405×10^{-9} kg-m²) = moment of
inertia of escape wheel and pinion
no. 3

$$IP = I_p = 0.1950 \times 10^{-7} \text{ in.-lb-sec}^2 \quad (2.207 \times 10^{-9} \text{ kg-m}^2) = \text{moment of inertia of pallet}$$

General Parameters

$$RC1 = r_{c1} = 0.0576 \text{ in. (1.463 mm)} = \text{distance from pivot of rotor to its center of mass}$$

$$RCP = r_{cp} = 0. = \text{pallet eccentricity}$$

$$RHOP = r_p = 0.0227 \text{ in. (0.577 mm)} = \text{pallet pivot radius}$$

$$RPM = 30,000 = \text{spin rate}$$

$$PHI1CD = \phi_{1c} = -120.134^\circ = \text{rotor angle in starting position (fig. 2)}$$

$$PSICCD = \psi_c = 0^\circ = \text{eccentricity angle of pallet}$$

$$PHID = 139^\circ = \text{escape wheel starting angle of initial coupled motion}$$

$$PHICUTD = 1485^\circ = \text{cumulative escape wheel angle obtained from product of total engaged rotor rotation and gear ratio. The total rotor rotation for the M739 fuze is } 46.41^\circ, \text{ while the gear ratio is 32. Thus, } PHICUTD = 46.41 \times 32 = 1485^\circ$$

$$MU = \mu = 0.10 = \text{coefficient of friction of gear train (pivots and tooth-to-tooth contacts) and escape wheel pivot}$$

$$MU1 = \mu_1 = 0.10 = \text{coefficient of friction of pallet-escape wheel interface and pallet pivot}$$

Gear Parameters

$$PSUBD1 = P_{d1} = 80 = \text{diametral pitch of mesh no. 1 (rotor and pinion no. 2)}$$

$$PSUBD2 = P_{d2} = 100 = \text{diametral pitch of mesh no. 2 (gear no. 2 and escape wheel pinion)}$$

$$NG1 = N_{G1} = 64 = \text{number of teeth of rotor (full gear no. 1)}$$

$$NG2 = N_{G2} = 36 = \text{number of teeth of gear no. 2}$$

$$NP2 = N_{p2} = 9 = \text{number of teeth of pinion no. 2}$$

$$NP3 = N_{p3} = 8 = \text{number of teeth of pinion no. 3 (escape wheel pinion)}$$

$CAPRP1 = R_{p1} = 0.41214 \text{ in. (10.468 mm)}$ = pitch radius of gear no. 1
 (rotor)

$CAPRP2 = R_{p2} = 0.19039 \text{ in. (4.836 mm)}$ = pitch radius of gear no. 2

$RP2 = r_{p2} = 0.05796 \text{ in. (1.472 mm)}$ = pitch radius of pinion no. 2

$RP3 = r_{p3} = 0.04231 \text{ in. (1.075 mm)}$ = pitch radius of pinion no. 3
 (escape wheel pinion)

$THETA1 = \theta_1 = 24.215^\circ$ = pressure angle of mesh no. 1

$THETA2 = \theta_2 = 27.326^\circ$ = pressure angle of mesh no. 2

$R1 = R_1 = 0.250 \text{ in. (6.350 mm)}$ = distance of rotor pivot from spin axis

$R2 = R_2 = 0.317 \text{ in. (8.052 mm)}$ = distance of pivot of gear and pinion
 set no. 2 from spin axis

$R3 = R_3 = 0.309 \text{ in. (7.849 mm)}$ = distance of pivot of escape wheel from
 spin axis

$R4 = R_4 = 0.304 \text{ in. (7.722 mm)}$ = distance of pivot of pallet from spin
 axis

$RH01 = \rho_1 = 0.03075 \text{ in. (0.781 mm)}$ = pivot radius of rotor

$RH02 = \rho_2 = 0.015 \text{ in. (0.381 mm)}$ = pivot radius of gear and pinion no. 2

$RH03 = \rho_3 = 0.015 \text{ in. (0.381 mm)}$ = pivot radius of escape wheel

$CAPRB1 = R_{b1} = 0.37588 \text{ in. (9.547 mm)}$ = base radius of gear no. 1

$CAPRB2 = R_{b2} = 0.16915 \text{ in. (4.296 mm)}$ = base radius of gear no. 2

$RB2 = r_{b2} = 0.05286 \text{ in. (1.343 mm)}$ = base radius of pinion no. 2

$RB3 = r_{b3} = 0.03759 \text{ in. (0.955 mm)}$ = base radius of escape wheel pinion

$CAPR01 = R_{01} = 0.41425 \text{ in. (10.522 mm)}$ = outside radius of gear no. 1

$CAPR02 = R_{02} = 0.19404 \text{ in. (4.929 mm)}$ = outside radius of gear no. 2

$R02 = r_{02} = 0.07670 \text{ in. (1.948 mm)}$ = outside radius of pinion no. 2

$R03 = r_{03} = 0.05580 \text{ in. (1.417 mm)}$ = outside radius of escape wheel
 pinion

$J1 = J_1 = 0$ = initialization parameter for mesh no. 1 [The zero value
 corresponds to earliest possible contact of mesh (ref 3).]

$J2 = J_2 = 0$ = initialization parameter for mesh no. 2

Output Data

The data blocks following the input data represent the results of various computations.

Fuze Geometry

The angles $BETA1D = \beta_1$ to $BETA3D = \beta_3$ and $GAMMA2D = \gamma_2$ to $GAMMA4D = \gamma_4$ are printed for checking purposes.

Coupled Motion

The first coupled motion output refers to the entrance side of the verge. For each time T of the coupled motion, the following variables are computed:

$PHI = \phi$ = instantaneous escape wheel angle (deg)

$PHIDOT = \dot{\phi}$ = escape wheel angular velocity (rad/sec)

$G = g$ = pallet - escape wheel contact position (in.) (equation C15 of appendix C)

$PSID = \psi$ = pallet angle (deg)

$PSIDOT = \dot{\psi}$ = pallet angular velocity (rad/sec)

$PHITOT = \phi_T$ = cumulative escape wheel angle (deg)

$F23 = F_{23}$ = normal contact force of gear no. 2 on pinion no. 3 (lb)

$F12 = F_{12}$ = normal contact force of gear no. 1 on pinion no. 2 (lb)

$PN = P_n$ = normal contact force between escape wheel and pallet (lb), computed according to equation B185 in appendix B

$PNPSI = P_n$ = normal contact force between escape wheel and pallet (lb), computed according to equation B186 in appendix B (serves for checking)

$DPHI2 = \ddot{\phi}$ = escape wheel angular acceleration (rad/sec²), Runge-Kutta output

Free Motion

The first free motion on the exit side follows the coupled motion on the entrance side of the verge. For each time T of the free motion, the following variables are evaluated:

$\text{PHI} = \phi$ = instantaneous escape wheel angle (deg)

$\text{PHIDOT} = \dot{\phi}$ = escape wheel angular velocity (rad/sec)

$\text{PSI} = \psi$ = pallet angle (deg)

$\text{PSIDOT} = \dot{\psi}$ = pallet angular velocity (rad/sec)

$\text{PHITOT} = \phi_T$ = cumulative escape wheel angle (deg)

$\text{FF12} = F_{F12}$ = normal contact force of gear no. 1 on pinion no. 2 for free motion (lb)

$\text{FF23} = F_{F23}$ = normal contact force of gear no. 2 on escape wheel pinion for free motion (lb)

Impact

The first exit impact follows the first exit free motion. Just preceding the "IMPACT" label, the program prints the values of $\text{VP} = V_{\text{TNi}}$ and $\text{VS} = V_{\text{SNi}}$ which stand for the pre-impact velocity components, normal to the verge face, of both the pallet and escape wheel contact points (equations D13 and D15). Subsequent to the "IMPACT" label, the following variables are evaluated:

$\text{PHI} = \phi$ = instantaneous escape wheel angle (deg), same as before impact

$\text{PHIDOT} = \dot{\phi}$ = post-impact escape wheel angular velocity (rad/sec)

$\text{PSI} = \psi$ = pallet angle (deg), same as before impact

$\text{PSIDOT} = \dot{\psi}$ = post-impact pallet angular velocity (rad/sec)

$\text{PHITOT} = \phi_T$ = cumulative escape wheel angle (deg), same as before impact

$\text{VP} = V_{\text{TNf}}$ = post-impact normal velocity component of pallet at contact point (equation D15)

$\text{VS} = V_{\text{SNf}}$ = post-impact normal velocity component of escape wheel tooth at contact point (equation D13)

Note that in the present program, the post-impact VP is equal to VS since the coefficient of restitution is zero.

"Number of Turns-to-Arm" and Maximum Contact Forces

The "number of turns-to-arm" at 30,000 rpm is obtained with the help of that time T_{1485} which corresponds to the escape wheel angle $\text{PHICUTD} = 1485^\circ$. Thus,

$$\text{number of turns-to-arm} = \frac{30000}{60} \times 0.05156 = 25.8$$

The maximum non-impact contact forces for the total cycle, for both coupled and free motion, are listed at the end of the output.

CONCLUSIONS

While it was not the purpose of this investigation to undertake a parametric study of the mechanism for which the program was written, the program was sufficiently tested to confirm that such a study is possible. It may include variations in masses and moments of inertia of all components; variations in the locations of the centers of mass of the verge and the rotor; and variations of gear, escapement, and fuze geometries; as well as various friction and coefficient of restitution conditions.

Previous high-speed motion picture observations of pin pallet escapements showed that the impacts were essentially inelastic and that, therefore, a zero coefficient of restitution was justified. Similar observations made on the detached lever escapement of the M577 fuze timer confirmed this.

The present work reports only on a single test run using the M739 fuze S&A data with a system coefficient of friction of 0.1. This is assumed to be representative of actual test conditions since (1) previous simulations of pin pallet escapements showed that the range of actual experimental results may be reproduced with coefficients of friction between 0.1 and 0.2 and (2) a special lubricant is used in conjunction with the M739 fuze. This choice of coefficient of friction is borne out by the good agreement with experimental results.

Noteworthy is the fact that the mechanism armed in approximately 22 turns with a coefficient of friction of 0.05 and in approximately 31 turns with a coefficient of friction of 0.15.

REFERENCES

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2. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.
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APPENDIX A
COMPUTER PROGRAM SANDA2V

PROGRAM SANDA2V		74/74	OPT=1	FTN 4.8+508	06/08/82	13.52.46	PAGE	1
1	PROGRAM SANDA2V(INPUT, OUTPUT, TAPES=INPUT, TAPE6=OUTPUT)							
	COTCON A,B,C,R,ALPHR,N1,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE							
	1LYA,PHITOT,PHIPR,N31,N32,OMEGA,DW2,RC1,PHIC,TEST1,TEST2,NG1,NG2,N							
5	2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R							
	3H03,RHOP,J1,J2,GAMMA2,GAMMA3P,GAMMA3,GAMMA4,GAMMA5,DELTA2,DE							
	ALTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH							
	SA1,ALPHA2,IN,T2,T3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPH12,DPS12,F							
	623MAX,F12MAX,FF23MAX,FF12MAX,P1MAX,P1N,ALPHEN,ALPHEX							
10	COTCON 7ZETA/ PSI,TIME,G,DPS1,GP,PHICUTD							
	DIMENSION AUX(8,2), AUX2(8,4), PRMT(5), PHI(2), DPHI(2), X(4), DX(
	14)							
	REAL M1,M2,M3,MP,I1,I2,I3,IP,LAMBDA,K,N31,N32,J1,J2,NG1,NG2,NP2,NP							
	13,MU,MU1,NT,N							
15	EXTERNAL FCT,OUTP,FCTF,OUTPF							
	C							
	C							
	READ IN AND WRITE DATA							
	C							
20	READ (5,17) A,B,C,ALPHEN,ALPHEX,NT,CONFIG							
	WRITE (6,18) A,B,C,ALPHEN,ALPHEX,NT,CONFIG							
	READ (5,19) EREST,LAMBDA,N							
	WRITE (6,20) EREST,LAMBDA,N							
	READ (5,21) M1,M2,M3,MP							
	WRITE (6,22) M1,M2,M3,MP							
25	READ (5,21) I1,I2,I3,IP							
	WRITE (6,23) I1,I2,I3,IP							
	READ (5,24) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MU1							
	WRITE (6,25) RC1,RCP,RHOP,RPM,PHI1CD,PSICCD,PHID,PHICUTD,MU,MU1							
	READ (5,26) PSUBD1,PSUBD2,NG1,NG2,NP2,NP3,CAPRP1,CAPRP2,RP2,RP3,TH							
30	1ETA1,THETA2							
	WRITE (6,29) PSUBD1,PSUBD2,NG1,NG2,NP2,NP3,CAPRP1,CAPRP2,RP2,RP3,T							
	1THETA1,THETA2							
	READ (5,27) R1,R2,R3,R4							
	WRITE (6,30) R1,R2,R3,R4							
35	READ (5,19) RHO1,RHO2,RHO3							
	WRITE (6,31) RHO1,RHO2,RHO3							
	READ (5,27) CAPRB1,CAPRB2,RB2,RB3							
	WRITE (6,32) CAPRB1,CAPRB2,RB2,RB3							
	READ (5,27) CAPRO1,CAPRO2,RO2,RO3							
40	WRITE (6,33) CAPRO1,CAPRO2,RO2,RO3							
	READ (5,28) J1,J2							
	WRITE (6,34) J1,J2							
	C							
	C							
45	INITIALIZATION OF PARAMETERS AND CONVERSION TO RADIAN							
	C							
	TIME=0.							
	PHITOT=0.							
	PHIPR=PHID							
	DPH12=0.							
	DPS12=0.							
50	F23MAX=0.							
	F12MAX=0.							
	FF23MAX=0.							
	FF12MAX=0.							
55	P1=3.14159							
	ZZ=PI/180.							
	OMEGA=RPM*2.*PI/60.							
	A							

```

OM2=OMEGA*OMEGA
PHI1C=PHI1CD*ZZ
PSIC=PSICD*ZZ
PSIC=PSIC
ALPHEN=ALPHEN*ZZ
ALPHEX=ALPHEX*ZZ
DELTA=360./N

60      C      COMPUTATION OF GEAR RATIOS
        C      N31=NP2*NP3/(NG1*NG2)
        C      N32=-NP3/NG2

70      C      DETERMINATION OF SIGNUM FUNCTION S6
        C      IF (CONFIG.EQ.1.) S6=1.
        C      IF (CONFIG.EQ.2.) S6=-1.

75      C      COMPUTATION OF GAMMAS AND BETAS
        C      GAMMA2=S6*ACOS((R1+R1+R2+R2-(CAPRP1+RP2)**2)/(2.*R1+R2))
        C      GAMMA3P=ACOS((R2+R2+R3+R3-(CAPRP2+RP3)**2)/(2.*R1+R2))
        C      GAMMA3=GAMMA2+S6*GAMMA3P
        C      GAMMA4P=ACOS((R3+R3+R4+R4-A*A)/(2.*R3+R4))
        C      GAMMA4=GAMMA3+S6*GAMMA4P
        C      GAMMA2D=GAMMA2/ZZ
        C      GAMMA3D=GAMMA3/ZZ
        C      GAMMA4D=GAMMA4/ZZ
        C      DELTA2=ACOS(((CAPRP1+RP2)**2+R1+R1-R2+R2)/(2.*R1*(CAPRP1+RP2)))
        C      DELTA3=ACOS(((CAPRP2+RP3)**2+R2+R2-R3+R3)/(2.*R2*(CAPRP2+RP3)))
        C      DELTA4=ACOS((A*A+R3+R3-R4+R4)/(2.*A+R3))
        C      BETA1=PI-S6*DELTA2
        C      BETA2=GAMMA2+PI-S6*DELTA3
        C      BETA3=GAMMA3+PI-S6*DELTA4
        C      IF (CONFIG.EQ.1.) GAMAPP=DELTA4+GAMMA4P
        C      IF (CONFIG.EQ.2.) GAMAPP=2.*PI-DELTA4-GAMMA4P
        C      BETA1D=BETA1/ZZ
        C      BETA2D=BETA2/ZZ
        C      BETA3D=BETA3/ZZ
        C      WRITE (6,35) BETA1D,BETA2D,BETA3D,GAMMA2D,GAMMA3D,GAMMA4D

100     C      CONVERSION OF PRESSURE ANGLES TO RADIAN
        C      THETA1=THETA1*ZZ
        C      THETA2=THETA2*ZZ

105     C      COMPUTATION OF CENTRIFUGAL FORCES
        C      T2=M2+R2*OM2
        C      T3=M3+R3*OM2

110     C      DETERMINATION OF GEAR TRAIN CONSTANTS
        C      TEST1=TAN(THETA1)
        C      TEST2=TAN(THETA2)
        C      D1=((CAPR1+R2)*TAN(THETA1))
        C      D2=((CAPR2+R3)*TAN(THETA2))

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PROGRAM SANDA2V		74/74	OPT=1	FTN 4.8+S08	06/08/82	13.52.46	PAGE	3
115	C	DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS						A 115
	C	CALL ALFA (CAPRB1,RB2,THETA1,CAPRO1,RO2,AL1IN,AL1FIN)						A 116
	C	CALL ALFA (CAPRB2,RB3,THEIA2,CAPRO2,RO3,AL2IN,AL2FIN)						A 117
120	C	INITIALIZATION OF ALPHAS						A 118
	C	ALPHA1=AL1IN+(AL1FIN-AL1IN)*J1						A 119
	C	ALPHA2=AL2IN+(AL2FIN-AL2IN)*J2						A 120
125	C	DATA FOR RUNGE KUTTA						A 121
	C	ALPHR=ALPHEN						A 122
	C	PRMT(2)=3.						A 123
130	C	PRMT(4)=.01						A 124
	C	NDIM=2						A 125
	C	NDIM2=4						A 126
	C	PHI(1)=PHID*ZZ						A 127
	C	PHI(2)=0.						A 128
135	C	COUPLED MOTION						A 129
	C	1 PRMT(1)=TIME						A 130
	C	PRMT(3)=.00001						A 131
140	C	DPHI(4)=.5						A 132
	C	DPHI(2)=.5						A 133
	C	IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 2						A 134
	C	WRITE (6,36)						A 135
145	C	2 CALL RKGS (PRMT,PHI,DPHI,NDIM,IHLF,FCT,OUTP,AUX)						A 136
	C	IF (PHITOT.GT.PHICUTD) GO TO 16						A 137
	C	TEST FOR ENTRANCE OR EXIT ACTION						A 138
150	C	IF (PH-LE-0.) GO TO 5						A 139
	C	PHID=PHI(1)/ZZ						A 140
	C	IF (PHID.GE.130.00.AND.PHID.LE.160.) GO TO 3						A 141
	C	GO TO 4						A 142
155	C	3 PHI(1)=PHI(1)+DELTA*ZZ*NT						A 143
	C	PHIPR=PHI(1)/ZZ						A 144
	C	PSI=PSI+2.*PI-LAMBDA*ZZ						A 145
	C	PSIC=PSIC+LAMBDA*ZZ						A 146
	C	ALPHR=ALPHEN						A 147
	C	GO TO 5						A 148
160	C	4 PHI(1)=PHI(1)-DELTA*ZZ*(NT+1.)						A 149
	C	PHIPR=PHI(1)/ZZ						A 150
	C	PSI=PSI-2.*PI+LAMBDA*ZZ						A 151
	C	PSIC=PSIC-LAMBDA*ZZ						A 152
	C	ALPHR=ALPHEN						A 153
	C	PSIC=PSIC						A 154
165	C	FREE MOTION						A 155
	C	5 PRMT(1)=TIME						A 156
	C	X(1)=PHI(1)						A 157
	C	X(2)=PHI(2)						A 158
170	C	X(3)=PSI						A 159
	C	X(4)=DPSI						A 160
	C							A 161
	C							A 162
	C							A 163
	C							A 164
	C							A 165
	C							A 166
	C							A 167
	C							A 168
	C							A 169
	C							A 170
	C							A 171

175		DX(1)=.25 DX(2)=.25 DX(3)=.25 DX(4)=.25 PRMT(3)=.00001 IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 6 WRITE (6,37) 6 CALL RKGS (PRMT,X,DX,NDIM2,IHLF,FCTF,OUTPF,AUX2) IF (PHITOT.GT.PHICUTD) GO TO 16 PHI(1)=X(1) PHI(2)=X(2) PSI=X(3) DPSI=X(4) G=(B*SIN(PHI(1))-C*SIN(PSI))/SIN(PSI+ALPHR) PHIG=PHI(1)/ZZ IF (PHID.LT.160..AND.GP.GT.0.) GO TO 10 IF (PHID.GT.160..AND.GP.LT.0.) GO TO 8 IF (PHID.LT.160.) GO TO 7 PHI(1)=PHI(1)-DELTA*ZZ*(NT+1.) PHIPR=PHI(1)/ZZ PSI=PSI-2.*PI*LAMBDA*ZZ PSIC=PSICC GO TO 5 7 PHI(1)=PHI(1)+DELTA*ZZ*NT PHIPR=PHI(1)/ZZ PSI=PSI+2.*PI-LAMBDA*ZZ PSIC=PSICC+LAMBDA*ZZ GO TO 5 EXIT ACTION COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION 8 VP=DPSI*(C*COS(ALPHR)+G) VS=PHI(2)*B*COS(PHI(1)-PSI-ALPHR) IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 9 WRITE (6,38) VP,VS EXIT ACTION TESTS 9 IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 12 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5 IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 12 IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1 IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 12 IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5 IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1 IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5 COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION 10 VP=DPSI*(C*COS(ALPHR)+G) VS=PHI(2)*B*COS(PHI(1)-PSI-ALPHR) IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 11 WRITE (6,38) VP,VS ENTRANCE ACTION	A 172 A 173 A 174 A 175 A 176 A 177 A 178 A 179 A 180 A 181 A 182 A 183 A 184 A 185 A 186 A 187 A 188 A 189 A 190 A 191 A 192 A 193 A 194 A 195 A 196 A 197 A 198 A 199 A 200 A 201 A 202 A 203 A 204 A 205 A 206 A 207 A 208 A 209 A 210 A 211 A 212 A 213 A 214 A 215 A 216 A 217 A 218 A 219 A 220 A 221 A 222 A 223 A 224 A 225 A 226 A 227 A 228
200	C C C C C		
205	C C C C		
210	C C C		
215	C C C		
220	C C C		
225	C C		


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230      C      11 IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
           IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
           IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 12
           IF (PHI(2).LE.0..AND.DPSI.GE.0.) GO TO 5
           IF (PHI(2).GE.0..AND.DPSI.LE.0.) GO TO 12
235      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
           IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 12
           IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
           C      IMPACT
240      C
           C      12 CALL IMPACT (PHI(1),PHI(2),PSI,DPSI)
           IF (TIME.GT.5.0) GO TO 16
245      C      TEST FOR EXIT ACTION
           C
           C      PHID=PHI(1)/ZZ
           IF (PHID.LE.160.0) GO TO 14
250      C      EXIT ACTION
           C
           C      COMPUTATION OF VELOCITIES VP AND VS FOR EXIT ACTION
           VP=DPSI*(C+COS(ALPHR)+G)
           VS=PHI(2)*B+COS(PHI(1)-PSI-ALPHR)
           IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 13
255      WRITE (6,38) VP,VS
           C      13 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
           C
           C      EXIT ACTION TESTS
           C
260      IF (PHI(2).GE.0..AND.DPSI.GE.0.) GO TO 1
           IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
           IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
           IF (PHI(2).GE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
           IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
           IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
           IF (PHI(2).LE.0..AND.DPSI.GT.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
           IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
           C
           C      COMPUTATION OF VELOCITIES VP AND VS FOR ENTRANCE ACTION
270      C
           C      14 VP=DPSI*(C+COS(ALPHR)+G)
           VS=PHI(2)*B+COS(PHI(1)-PSI-ALPHR)
           IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 15
           WRITE (6,38) VP,VS
275      C      15 IF (ABS(ABS(VP)-ABS(VS)).LT.2.0) GO TO 1
           C
           C      ENTRANCE ACTION TESTS
           C
280      IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 5
           IF (PHI(2).GE.0..AND.DPSI.GE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 1
           IF (PHI(2).LE.0..AND.DPSI.GE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
           IF (PHI(2).LE.0..AND.DPSI.LE.0.) GO TO 5
           IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).GT.ABS(VS)) GO TO 1
           IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).LT.ABS(VS)) GO TO 5
285      IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1

```

IF (PHI(2).LE.0..AND.DPSI.LE.0..AND.ABS(VP).EQ.ABS(VS)) GO TO 1
16 TURNSEBEN=TIME/60.

WRITE (6,39) F23MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,TURNS
STOP

290 C

C

C

17 FORMAT (7E10.5)

18 FORMAT (1H1,5X,2HA=,F13.5,5X,2HB=,F13.5,5X,2HC=,F13.5,5X,7HALPHEN=
1,F9.4,5X,7HALPHEX=,F9.4//6X,3HNT=,F3.0,5X,8HCONFIG=,F3.0//)

295

19 FORMAT (3F10.5)

20 FORMAT (1H,5X,6HEREST=,F5.2,3X,7HLAMBDA=,F8.3,3X,3HN=,F4.0//)

296

21 FORMAT (4E12.5)

22 FORMAT (1H,5X,4HM1=,E15.5,3X,4HM2=,E15.5,3X,4HM3=,E15.5,3X,4HM=
1P=,E15.5//)

300

23 FORMAT (1H,5X,4HI1=,E15.5,3X,4HI2=,E15.5,3X,4HI3=,E15.5,3X,4HI=
1P=,E15.5//)

24 FORMAT (7F10.4/3F10.4)

25 FORMAT (6X,5HRC1=,F7.4,3X,5HRCP=,F7.4,3X,6HRHOP=,F7.4,3X,5HRPM=
1=,F6.0,3X,8HPH1CD=,F9.4,3X,8HPSIGCD=,F9.4,3X,6HPHID=,F9.4//6X,

305

29HPHICUTD=,F6.0//6X,4HMU=,F4.2,3X,5HMU1=,F4.2//)

26 FORMAT (2F10.4/4F10.0/4F10.5/2F10.4)

27 FORMAT (4F10.4)

28 FORMAT (2F10.2)

29 FORMAT (1H,5X,8HPSUBD1=,F5.1,3X,8HPSUBD2=,F5.1//6X,5HNG1=,F4.0
1,3X,5HNG2=,F4.0,3X,5HNP2=,F4.0,3X,5HNP3=,F4.0//6X,8HCAPRP1=,F8
2.5,3X,8HCAPRP2=,F8.5//6X,5HRP2=,F8.5,3X,5HRP3=,F8.5//6X,8HTHETA

310

31=,F8.3,3X,8HTHETA2=,F8.3//)

30 FORMAT (6X,4HRT=,F7.5,3X,4HR2=,F7.5,3X,4HR3=,F7.5,3X,4HR4=,F7.
15//)

31 FORMAT (6X,6HRHO1=,F7.5,3X,6HRHO2=,F7.5,3X,6HRHO3=,F7.5//)

32 FORMAT (6X,6HCAPRB1=,F7.5,3X,6HCAPRB2=,F7.5,3X,5HRB2=,F7.5,3X,5
1HRB3=,F7.5//)33 FORMAT (6X,6HCAPRO1=,F7.5,3X,6HCAPRO2=,F7.5,3X,5HRO2=,F7.5,3X,5
1HRO3=,F7.5//)

34 FORMAT (1H,5X,4HJ1=,F4.2,3X,4HJ2=,F4.2//)

35 FORMAT (6X,8HBETA1D=,F7.2,3X,8HBETA2D=,F7.2,3X,8HBETA3D=,F7.2/5
1X,9HGAMMA2D=,F7.2,3X,9HGAMMA3D=,F7.2,3X,9HGAMMA4D=,F7.2//)

36 FORMAT (1H0,5X,14HCUPLED MOTION)

37 FORMAT (1H0,5X,11HFREE MOTION//)

38 FORMAT (4H0VP=,F8.3,3X,3HVS=,F8.3)

39 FORMAT (1H0,6X,8HF23MAX=,F6.2/1H0,6X,8HF12MAX=,F6.2/1H0,6X,9HFF2
13MAX=,F6.2/1H0,6X,9HFF12MAX=,F6.2/1H0,6X,7HPNMAX=,F6.2//6X,23HN

20NUMBER OF TURNS TO ARM=,F8.3)

END

330

A 286

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SUBROUTINE IMPACT	74/74	OPT=1	FTN 4.8+508	06/08/82	13.52.48	PAGE	1
1	SUBROUTINE IMPACT (PHI,DPHI,PSI,DPSI) COMMON A,B,C,R,ALPHR,PI,ZZ,M1,N2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE						B 1
	1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N						B 2
	2P2,NP3,CAPR81,CAPR82,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R						B 3
5	3HO3,PHOP,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,DELTA2,DE						B 4
	4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH						B 5
	5A1,ALPHA2,IN,I2,I3,MU,MU1,RCP,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F						B 6
	623MAX,E12MAX,E23MAX,E12MAX,PNMAX,PN,ALPHEN,ALPHEX						B 7
	REAL I1,I2,I3,IP,LAMBDA,N31,N32,ISTOT,K						B 8
10	ISTOT=I3+I2*N32+N32+I1*N31*N31						B 9
	G=(B*SIN(PHI)-C*SIN(PSI))/SIN(PSI+ALPHR)						B 10
	ADNE=B*COS(PHI-PSI-ALPHR)						B 11
	DONE=C*COS(ALPHR)+G						B 12
	DPHIIN=DPHI						B 13
15	DPHI=(IP*ADNE*DPSI+ISTOT*DONE+DPHI+IP*ADNE*EREST/DONE*(DPSI*DONE-D						B 14
	1PHI*ADNE))/(IP*ADNE**2/DONE+ISTOT*DONE)						B 15
	DPSI=(DPHI*ADNE-EREST*(DPSI*DONE-DPHIIN*ADNE))/DONE						B 16
	PHID=PHI/ZZ						B 17
	PSID=PSI/ZZ						B 18
20	IF (PHITOT.GT.30..AND.PHIOT.I1.1450..) GO TO 1						B 19
	WRITE (6,2)						B 20
	WRITE (6,3) PHID,DPHI,PSID,DPSI,PHITOT						B 21
	1 RETURN						B 22
	C						B 23
25	C						B 24
	C						B 25
	2 FORMAT (1H0,5X,6HIMPACT)						B 26
	3 FORMAT (1H0,18X,4HPI=,F8.3,3X,7HPHIDOT=,F8.3,3X,4HPHI=,F8.3,3X,7H						B 27
30	1PSIDOT=,F8.3,3X,6HPHIOT=,F8.3)						B 28
	END						B 29
	B 30-						B 30-

SUBROUTINE FCT	74/74	OPT=1	FTN 4.8+508	06/09/82	13.52.48	PAGE	1
1	SUBROUTINE FCT (T, PHI, DPHI)						C 1
	COMMON A,B,C,R,ALPHA,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,ERESI,LAMBDA,DE						C 2
	1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,N						C 3
5	2P2,NP3,CAPR81,CAPR82,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R						C 4
	3HO3,RHO4,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,DELTA2,DE						C 5
	4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH						C 6
	SA1,ALPHA2,IN,T2,T3,MU,MU1,RC,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPS12,F						C 7
	623MAX,F12MAX,FE12MAX,ENMAX,PN,ALPHEN,ALPHEX						C 8
10	DIMENSION PHI(2),DPHI(2)						C 9
	REAL M1,M2,M3,MP,I1,I2,I3,IP,I1R,N31,N32,MU,MU1,IPR						C 10
	PHID=PHI(1)/ZZ						C 11
	DELPHI=PHID-PHIPR						C 12
	PHIT=(PHITOT+DELPHI)*ZZ						C 13
15	IN=1						C 14
	CALL KINEM (A,B,ALPHR,PHI,C,G,P,Q,S,PSI,DPSI,ACNE,BONE,DONE,U						C 15
	1,V,VST)						C 16
	CALL IN2 (PHI(2),PHIT,DELPHI,YST,PSI,DPSI,ACNE,BONE,DONE,AA1,						C 17
	1AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16						C 18
20	2,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29,						C 19
	3AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,A						C 20
	4AA3,AA44)						C 21
	IF (DPSI*DPSI2.GE.0.) IPR=IP+AA22						C 22
	IF (DPSI*DPSI2.LT.0.) IPR=IP-AA22						C 23
25	IF (PHI(2)*DPHI2.GE.0.) I1R=I1+MU*RHO1*(AA26+AA30)						C 24
	IF (PHI(2)*DPHI2.LT.0.) I1R=I1-MU*RHO1*(AA26+AA30)						C 25
	IF (I1R.LT.0.) I1R=0						C 26
	IF (IPR.LT.0.) IPR=0						C 27
30	AA45=I3*AA18+IPR*AA17*U-(I2*N32-AA42*I1R*N31/AA31)*AA15*AA18/AA44						C 28
	AA46=IPR*AA17+V+AA17*AA21*U+AA15*AA18*AA34*AA42*N31*N31/(AA31*AA						C 29
	144)						C 30
	AA47=2.*OM2*AA17*AA20*U/ABS(OMEGA)+AA15*AA18*AA33*AA42*N31/(AA31*AA						C 31
	1A44)						C 32
	AA48=-AA15*AA18*AA32*AA42/(AA31*AA44)-AA15*AA18*AA43*T2/AA44-AA16*						C 33
35	1AA18*T3-OM2*AA17*AA19						C 34
	AA49=AA15*AA18*AA35*AA42/(AA31*AA44)						C 35
	AA50=MP*RCR*R4*AA17*OM2						C 36
	DPHI(1)=PHI(2)						C 37
	DPHI(2)=(-AA46*PHI(2)+PHI(2)*AA47*PHI(2)+AA48-AA49*SIN(PHI1C*N31*(C 38
40	1PHITOT*ZZ+PHI(1)-PHIPR*ZZ)+AA50*SIN(GAMAPP-PSI-PSIC))/AA45						C 39
	RETURN						C 40
	END						C 41

SUBROUTINE	OUTP	74/74	OPT=1	FTN 4.8+508	06/08/82	13.52.48	PAGE	1
1				SUBROUTINE OUTP (I,PHI,DPHI,IHLF,NDIM,PRMT) REAL M1,M2,M3,MP,J1,I2,I3,IP,IIR,N31,N32,MU,MU1,IPR DIMENSION PHI(2),DPHI(2),PRMT(5) COMMON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE 11IA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,IESI1,IESI2,NG1,NG2,N 2P2,NP3,CAPR81,CAPR82,RB2,RB3,THETA1,THETA2,R1,R2,R3,R4,RHO1,RHO2,R 3HO3,RHOP,J1,J2,GAMMA2,GAMMA3P,GAMMA3,GAMMA4,GAMMA5,DELTA2,DE 41A3,DELTA4,BEIA1,BEIA2,BEIA3,DI,D2,AL1IN,AL1EIN,AL2FIN,ALPH 5A1,ALPHA2,IN,T2,T3,MU,MU1,RC,PSIC,S1,S2,S4,S5,A1,A2,DPHI2,DPSI2,F 623MAX,F12MAX,FF23MAX,FF12MAX,PNMAX,PN,ALPHEN,ALPHEX CDEMON,ZEIA/PSI,LINE,G,DPSI,GP,PHICUD PHID=PHI(1)/ZZ DELPHI=PHID-PHIPR PHIPR=PHID 15 PHITOT=PHITOT+DELPHI PHIT=PHITOT+ZZ IN=0 CALL KINEM (A,B,ALPHR,PHI,C,G,P,Q,S,PSI,DPSI,ACONE,BONE,CONE,DOME,U 1,V,VST) CALL IN2 (PHI(2),PHIT,DELPHI,VSI,PSI,DPSI,ACONE,BONE,CONE,DOME,AA1, 1AA2,AA3,AA4,AA5,AA6,AA7,AA8,AA9,AA10,AA11,AA12,AA13,AA14,AA15,AA16 2,AA17,AA18,AA19,AA20,AA21,AA22,AA23,AA24,AA25,AA26,AA27,AA28,AA29, 3AA30,AA31,AA32,AA33,AA34,AA35,AA36,AA37,AA38,AA39,AA40,AA41,AA42,A 4AA3,AA44) 25 IF (DPSI+DPSI2.GE.0.) IPR=IP+AA22 IF (DPSI+DPSI2.LT.0.) IPR=IP-AA22 IF (PHI(2)*DPHI2.GE.0.) IIR=I1+ABS(MU)*RHO1*(AA26+AA30) IF (PHI(2)*DPHI2.LT.0.) IIR=I1-ABS(MU)*RHO1*(AA26+AA30) IF (IIR-LT.0.) IIR=0. IF (IPR.LT.0.) IPR=0. 30 AA45=I3+AA18+IPR*AA17*U-(I2+N32-AA42+I1R*N31/AA31)*AA15+AA18/AA44 AA46=IPR*AA17+V+AA17*AA21+U+AA15+AA18*AA34+AA42*N31/(AA31*AA 144) AA47=2.*OM2*AA17*AA20*U/ABS(OMEGA)+AA15+AA18*AA33*AA42*N31/(AA31*A 1AA4) AA48=-AA15+AA18+AA32*AA42/(AA31*AA44)-AA15+AA18*AA43*T2/AA44-AA16* 1AA18+T3-OM2*AA17*AA19 AA49=AA15+AA18+AA35*AA42/(AA31*AA44) AA50=MP+RCP*R4+AA17*OM2 40 DPHI2=(-AA46+PHI(2)*PHI(2)-AA47*PHI(2)+AA48-AA49+SIN(PHI1C+N31*(PH 1TOT+ZZ+PHI(1)-PHIPR+ZZ))+AA50*SIN(GAMMA5-PSI-PSIC))/AA49 DPSI2=U+DPHI2+V+PHI(2)*PHI(2) C C 45 COMPUTATION OF CONTACT FORCES C C F23=(-AA32*AA42/AA31-T2*AA43-AA33*AA42+N31*PHI(2)/AA31-AA42*AA34+N 131*N31*PHI(2)*PHI(2)/AA31-AA35*AA42*SIN(PHI1C+N31*PHIT)/AA31+(I2+N 232-AA42+I1R*N31/AA31)*DPHI2)/AA44 F12=(F23+AA44+T2*AA43-I2*N32*DPHI2)/AA42 50 PN=(-I3*DPHI2+F23+AA15-T3*AA16)/ART7 IF (F23.GT.F23MAX) F23MAX=F23 IF (F12.GT.F12MAX) F12MAX=F12 IF (PN.GT.PNMAX) PNMAX=PN PNPSI=(IPR+DPSI2+AA21+DPSI+DPSI+2.*OM2*DPSI+AA20/ABS(OMEGA))+OM2*AA 119-MP+RCP*R4+OM2*SIN(GAMMA5-PSI-PSIC))/AA18 55 C C TEST FOR CONTINUATION OF COUPLED MOTION C 56 D 57 D				

C

60 IF (PHID.GT.150.) GO TO 1
IF (.NOT.(G.GE.0..AND.PN.GT.0.)) PRMT(5)=1.
GO TO 2

1 IF (.NOT.(G.IE.0..AND.PN.GT.0.)) PRMT(5)=1.

C

WRITE OUTPUT

C

65 2 IF (PHITOT.GT.30..AND.PHITOT.LT.1450.) GO TO 3
PSID=PSI/ZZ

WRITE (6,5) I,PHID,PHI(2),G,PSID,DESI,PHITOT,F23,F12,PN,DNPSI,DPHI

12

70 3 IF (PHITOT.LT.PHICUTD) GO TO 4

PRMT(5)=1.

4 TIME=T

RETURN

C

C

C

5 FORMAT (6X,3H1 =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,3HG =,
1FG.4,3X,8HPSID =,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F7.2/20X,5H

2F23 =,F7.4,3X,5HF12 =,F7.4,3X,4HPN =,F7.4,3X,7HPNPSI =,F7.4,3X,7HD

3PHI2 =,E12.4)

END

D 58

D 59

D 60

D 61

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D 68

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D 79

D 80

D 81-

SUBROUTINE	OUTPF	74/74	OPT=1	FTN 4.8+508	06/08/82	13.52.46	PAGE	2
	C	CHECK FOR CONTINUED FREE MOTION						
60		F=A*SIN(X(3)+ALPHR)-B*SIN(X(1))-X(3)-ALPHR)-C*SIN(ALPHR)						F 58
		GP=A*COS(X(3)+ALPHR)+B*COS(X(1))-X(3)-ALPHR)-C*COS(ALPHR)						F 59
		IF (PHID.LI.145..AND.E.GT.0.) GO TO 2						F 60
		IF (PHID.GT.145..AND.F.LT.0.) GO TO 3						F 61
		PRMT(5)=1.						F 62
65		2 IF (GP.LI.0.) PRMT(5)=1.						F 63
		GO TO 4						F 64
		3 IF (GP.GT.0.) PRMT(5)=1.						F 65
		4 TIME=T						F 66
70		IF (PHITOT.LT.PHICUTD) GO TO 5						F 67
		PRMT(5)=1.						F 68
		5 RETURN						F 69
	C							F 70
	C							F 71
	C							F 72
75		6 FORMAT (6X,3HT =,F8.5,3X,5HPHI =,F7.2,3X,8HPHIDOT =,F7.2,3X,5HPSI						F 73
		1=,F7.2,3X,8HPSIDOT =,F8.2,3X,8HPHITOT =,F7.2/20X,6HFF12 =,F7.3,3X,						F 74
		26HEE23 =,F7.3)						F 75
		END						F 76
								F 77
								F 78-

```

1  SUBROUTINE KINEM (A,B,ALPHR,PHI,C,G,P,Q,S,PSI,DPSI,ACONE,BONE,CONE,
    1  IDONE,U,V,VST)
    DIMENSION PHI(2)
    PI=3.14159
    CAPA=A*COS(ALPHR)+B*COS(PHI(1)-ALPHR)
    CAPB=A*SIN(ALPHR)-B*SIN(PHI(1)-ALPHR)
    CAPC=C*SIN(ALPHR)
    PSI=2.*ATAN2((CAPA-SQRT(CAPA**2+CAPB**2-CAPC**2)),(CAPB+CAPC))
    IF (PSI.LT.0.) PSI=2.*PI+PSI
    G=(B*SIN(PHI(1))-C*SIN(PSI))/SIN(PSI+ALPHR)
    P=B*COS(PHI(1)-ALPHR-PSI)
    Q=A*COS(PSI+ALPHR)+B*COS(PHI(1)-ALPHR-PSI)
    U=P/Q
    V=1./Q**3*(A**2**2*SIN(PSI+ALPHR)-B*(P-Q)**2*SIN(PHI(1)-ALPHR-PSI))
    AONE=B*COS(PHI(1)-PSI-ALPHR)
    BONE=B*SIN(PHI(1)-PSI-ALPHR)
    CONE=-C*SIN(ALPHR)
    DONE=C*COS(ALPHR)+G
    DPSI=U*PHI(2)
    VSI=-PHI(2)*B*SIN(PHI(1)-PSI-ALPHR)-DPSI*C*SIN(ALPHR)
    RETURN
    END
    
```

SUBROUTINE IN2	74/74	OPT=1	FTN 4.8+508	06/08/82	13.52.48	PAGE	1
1			SUBROUTINE IN2 (DPHI, PHIT, DELPHI, VST, PSI, DPSI, ACNE, BONE, CONE, DONE, 1AA1, AA2, AA3, AA4, AA5, AA6, AA7, AA8, AA9, AA10, AA11, AA12, AA13, AA14, AA15, 2AA16, AA17, AA18, AA19, AA20, AA21, AA22, AA23, AA24, AA25, AA26, AA27, AA28, A 3AA29, AA30, AA31, AA32, AA33, AA34, AA35, AA36, AA37, AA38, AA39, AA40, AA41, AA 442, AA43, AA44)				
5			CONCON A,B,C,R,ALPHR,PI,ZZ,M1,M2,M3,MP,I1,I2,I3,IP,EREST,LAMBDA,DE 1LTA,PHITOT,PHIPR,N31,N32,OMEGA,OM2,RC1,PHI1C,TEST1,TEST2,NG1,NG2,M 2P2,NP3,CAPRB1,CAPRB2,RB2,RB3,THEIA1,THEIA2,R1,R2,R3,R4,RHO1,RHO2,R 3HO3,RHOP,J1,J2,GAMMA2,GAMMA3,GAMMA4,GAMMA5,GAMMA6,GAMMA7,GAMMA8, 4LTA3,DELTA4,BETA1,BETA2,BETA3,D1,D2,AL1IN,AL1FIN,AL2IN,AL2FIN,ALPH 5A1,ALPHA2,IN,I2,I3,MU,MU1,RC,PSIC,S1,S2,S4,S5,AL,A2,DPHI2,DPSI2,F 623MAX,F12MAX,F23MAX,MU1,RC,PSIC,S1,S2,S4,S5,AL,A2,DPHI2,DPSI2,F REAL M1,M2,M3,MP,MU,MU1,N31,N32,I1 IF (DPHI.EQ.0.) GO TO 1 MU=ABS(MU)*DPHI/ABS(DPHI) 1 IF (IN.EQ.0) GO TO 2				
15			1 IF (IN.EQ.0) GO TO 2				
20			UPDATE VALUES OF ALPHAS DELAL2=DELPHI*ZZ DELAL1=DELAL2*RB2/CAPRB1 ALPHA1=ALPHA1+DELAL1 ALPHA2=ALPHA2+DELAL2 IF (ALPHA1.GT.AL1FIN) ALPHA1=AL1IN IF (ALPHA2.GT.AL2FIN) ALPHA2=AL2IN				
25			IF (ALPHA1.GT.AL1FIN) ALPHA1=AL1IN IF (ALPHA2.GT.AL2FIN) ALPHA2=AL2IN				
30			DETERMINATION OF SIGNUMS 2 IF (ALPHA1.LT.TEST1) S1=-1. IF (ALPHA2.LT.TEST2) S2=-1. IF (ALPHA1.EQ.TEST1) S1=0. IF (ALPHA2.EQ.TEST2) S2=0. IF (ALPHA1.GT.TEST1) S1=-1. IF (ALPHA2.GT.TEST2) S2=-1. IF (VST.NE.0.) GO TO 2 S4=1. GO TO 4 3 S4=VST/ABS(VST) 4 IF (DPSI.NE.0.) GO TO 5 S5=1. GO TO 6 5 S5=DPSI/ABS(DPSI)				
40			COMPUTATION OF A1 AND A2 6 A1=ALPHA1+CAPRB1 A2=ALPHA2+CAPRB2 DENOM=1.+MU*MU DENOM1=1.+MU1*MU1				
45			COMPUTATION OF A1 AND A2				
50			COMPUTATION OF A1 AND A2				
55			AA2=ABS((MP*(R4*(SIN(GAMAPP)-MU1*S5*CDOS(GAMAPP))+RCP*(SIN(PSI+PSIC 1)-MU1*S5*CDOS(PSI+PSIC))))/DENOM1) AA3=ABS((MP*RCP*(SIN(PSI+PSIC))-MU1*S5*CDOS(PSI+PSIC)))/DENOM1 AA4=ABS((MP*RCP*(COS(PSI+PSIC)+MU1*S5*SIN(PSI+PSIC)))/DENOM1) AA6=ABS((MP*(-R4*(CDOS(GAMAPP)+MU1*S5*SIN(GAMAPP))-RCP*(COS(PSI+PSI 1)-MU1*S5*CDOS(PSI+PSIC))))/DENOM1				

1C)*MU1+S5*SIN(PSI+PSIC))/DENOM1)
AA7=ABS((MP*PCP*(COS(PSI+PSIC)+MU1+S5*SIN(PSI+PSIC)))/DENOM1)
AA8=ABS((MP*PCP*(SIN(PSI+PSIC)-MU1+S5*COS(PSI+PSIC)))/DENOM1)
AA10=ABS((-MU*(1.-S2)*SIN(BETA2+THETA2)-(1.+MU*MU*S2)*COS(BETA2+TH
ETA2))/DENOM1)
AA11=ABS((SIN(GAMMA3)-MU*COS(GAMMA3))/DENOM1)
AA13=ABS((-1.+MU*MU*S2)*SIN(BETA2+THETA2)+MU*(1.-S2)*COS(BETA2+TH
ETA2))/DENOM1)
AA14=ABS((COS(GAMMA3)+MU*SIN(GAMMA3))/DENOM1)
AA15=RB3-MU*(S2*(D2-A2)+RH03*(AA10+AA13))
AA16=MU*RH03*(AA11+AA14)
IF (ALPHR.EQ.ALPHEX) GO TO 7
AA1=ABS((-MU1*(S4+S5)*SIN(PSI+ALPHR)-(1.-S4+S5*MU1*MU1)*COS(PSI+AL
PHR))/DENOM1)
AA5=ABS((MU1*(S4+S5)*COS(PSI+ALPHR)+(1.-S4+S5*MU1*MU1)*SIN(PSI+ALP
HR))/DENOM1)
AA9=ABS(((MU1*S4+MU1)*SIN(PSI+ALPHR+BEIA3)+(1.-MU1*MU1*S4)*COS(PSI+AL
PHR+BEIA3))/DENOM1)
AA12=ABS(((1.-MU1*MU1*S4)*SIN(PSI+ALPHR+BEIA3)-(1.-MU1*MU1*S4)*COS(PSI+AL
PHR+BEIA3))/DENOM1)
AA17=ADNE-MU1*S4*BONE+MU1*RH03*(AA9+AA12)
AA18=DONE-CONE-MU1*S4-RHOP*MU1*S5*(AA1+AA5)
GO TO 8
7 AA1=ABS((MU1*(-S4+S5)*SIN(PSI+ALPHR)+(1.-S4+S5*MU1*MU1)*COS(PSI+AL
PHR))/DENOM1)
AA5=ABS((MU1*(S5-S4)*COS(PSI+ALPHR)-(1.-S4+S5*MU1*MU1)*SIN(PSI+ALP
HR))/DENOM1)
AA9=ABS(((MU1*S4+MU1)*SIN(PSI+ALPHR+BEIA3)-(1.-MU1*MU1*S4)*COS(PSI+AL
PHR+BEIA3))/DENOM1)
AA12=ABS(((1.-MU1*MU1*S4)*SIN(PSI+ALPHR+BEIA3)-(1.-MU1*MU1*S4)*COS(PSI+AL
PHR+BEIA3))/DENOM1)
AA17=-ADNE-MU1*S4*BONE+MU1*RH03*(AA9+AA12)
AA18=-DONE-CONE-MU1*S4-RHOP*MU1*S5*(AA1+AA5)
8 AA19=RHOP*MU1*S5*(AA2+AA6)
AA20=RHOP*MU1*(AA3+AA7)
AA21=S5*AA20
AA22=RHOP*MU1*(AA4+AA8)
AA23=ABS(((1.-MU1*MU1*S1)*SIN(BETA1-THETA1)-MU1*(1.+S1)*COS(BETA1-TH
ETA1))/DENOM1)
AA24=ABS((M1*(R1+RC1*(COS(PHI1C+N31*PHIT)+MU*SIN(PHI1C+N31*PHIT)))/DENOM1)
AA25=ABS((M1*RC1*(COS(PHI1C+N31*PHIT)+MU*SIN(PHI1C+N31*PHIT)))/DEN
10M)
AA26=ABS((M1*RC1*(SIN(PHI1C+N31*PHIT)-MU*COS(PHI1C+N31*PHIT)))/DEN
10M)
AA27=ABS((MU*(1.+S1)*SIN(BETA1-THETA1)+(1.-MU*MU*S1)*COS(BETA1-TH
ETA1))/DENOM1)
AA28=ABS((MU*M1+R1+M1*RC1*(MU*COS(PHI1C+N31*PHIT)-SIN(PHI1C+N31*PH
IT))/DENOM1)
AA29=ABS((M1*RC1*(MU*COS(PHI1C+N31*PHIT)-SIN(PHI1C+N31*PHIT)))/DEN
10M)
AA30=ABS((M1*RC1*(MU*SIN(PHI1C+N31*PHIT)+COS(PHI1C+N31*PHIT)))/DEN
10M)
AA31=CAPR81-MU*S1+A1+MU*RHO1*(AA23+AA27)
AA32=ON2-RHO1*MU*(AA24+AA28)
AA33=ON2/ABS(OMEGA)*2.*ABS(MU)*RHOT*(AA25+AA29)
AA34=MU*RHO1*(AA25+AA29)

115

AA35=M1*R1*RC1*DM2

H 115

AA36=ABS((1.-MU*MU*S2)*SIN(BETA2+THETA2)+MU*(1.+S2)*COS(BETA2+THE

H 116

1TA2))/DENOM)

H 117

AA37=ABS(((1.+MU*MU*S1)*SIN(BETA1-THETA1)+MU*(1.-S1)*COS(BETA1-THE

H 118

1TA1))/DENOM)

H 119

AA38=ABS((COS(GAMMA2)-MU*SIN(GAMMA2))/DENOM)

H 120

AA39=ABS((MU*(1.+S2)*SIN(BETA2+THETA2)-(1.-MU*MU*S2)*COS(BETA2+THE

H 121

1TA2))/DENOM)

H 122

AA40=ABS((MU*(1.-S1)*SIN(BETA1-THETA1)-(1.+MU*MU*S1)*COS(BETA1-THE

H 123

1TA1))/DENOM)

H 124

AA41=ABS((MU*COS(GAMMA2)+SIN(GAMMA2))/DENOM)

H 125

AA42=RB2-MU*(S1*(D1-A1)+RH02*(AA37+AA40))

H 126

AA43=MU*RH02*(AA38+AA41)

H 127

AA44=CAPR82-MU*(S2+A2-RH02*(AA36+AA39))

H 128

RETURN

H 129

END

H 130-

SUBROUTINE ALFA		74/74	OPT=1	FTN 4.8+508	06/08/82	13.52.46	PAGE	1
1	SUBROUTINE ALFA (CAPRB,RB,THETA,CAPRO,RG,ALIN,ALFIN)							1
	C							1
	C	THIS SUBROUTINE COMPUTES THE INITIAL AND FINAL VALUES OF ALPHAS						2
	C							3
5	ALIN=((CAPRB+RB)*TAN(THETA)-SQRT(RG*RG-RB*RB))/CAPRB						1	4
	ALFIN=SQRT(CAPRO*CAPRO-CAPRB*CAPRB)/CAPRB						1	5
	RETURN						1	6
	END						1	7
							1	8-

A = .22600 B = .16800 C = .13138 ALPHEN = 43.5352 ALPHEX = 29.2981
 NT = 4. CONFIG = 2.
 ERESI = 0.00 LAMBDA = 92.930 N = 22.
 M1 = .31850E-04 M2 = .32750E-05 M3 = .26310E-05 MP = .16400E-05
 I1 = .19670E-05 I2 = .40260E-07 I3 = .21250E-07 IP = .19500E-07
 RCI = .0576 RCP = 0.0000 RHOP = .0227 RPM = 30000 PHICD = 120.1340 PSICD = 0.0000 PHID = 138.0000
 PHICUTO = 1485.
 MU = .10 MU1 = .10
 PSUB01 = 80.0 PSUB02 = 100.0
 NG1 = 64. NG2 = 36. NP2 = 9. NP3 = 8.
 CAPR01 = .41214 CAPR02 = .19039
 RP2 = .05706 RP3 = .04231
 THETA1 = 24.215 THETA2 = 27.326
 R1 = .25000 R2 = .31700 R3 = .30900 R4 = .30400
 RH01 = .03075 RH02 = .01500 RH03 = .01500
 CAPR01 = .37588 CAPR02 = .16915 R82 = .05286 R83 = .03759
 CAPR01 = .41425 CAPR02 = .19404 R02 = .07670 R03 = .05580
 J1 = 0.00 J2 = 0.00
 BETA10 = 218.87 BETA20 = 134.90 BETA30 = 92.11
 GAMMA20 = 111.47 GAMMA30 = 155.09 GAMMA40 = 188.34

COUPLED MOTION

T = 0.00000	PHI = 139.00	PHIDOT = 0.00	G = .0222	PSID = 42.08	PSIDOT = 0.00	PHITOT = -.00
F23 = 2.4663	F12 = 9.6322	PN = .3312	PNPSI = .3312	DPHI2 = .1568E+07	PSIDOT = 5.42	PHITOT = .00
T = .00001	PHI = 139.00	PHIDOT = 6.35	G = .0222	PSID = 42.08	PSIDOT = .3305	PHITOT = .00
F23 = 2.5031	F12 = 9.6925	PN = .3305	PNPSI = .3305	DPHI2 = .1212E+07	PSIDOT = 10.59	PHITOT = .00
T = .00001	PHI = 139.00	PHIDOT = 12.41	G = .0222	PSID = 42.08	PSIDOT = .3306	PHITOT = .00
F23 = 2.5031	F12 = 9.6925	PN = .3306	PNPSI = .3306	DPHI2 = .1212E+07	PSIDOT = 15.76	PHITOT = .01
T = .00002	PHI = 139.01	PHIDOT = 18.47	G = .0222	PSID = 42.09	PSIDOT = .3309	PHITOT = .01
F23 = 2.5037	F12 = 9.6924	PN = .3309	PNPSI = .3309	DPHI2 = .1213E+07	PSIDOT = 20.93	PHITOT = .01
T = .00002	PHI = 139.01	PHIDOT = 24.53	G = .0222	PSID = 42.09	PSIDOT = .3310	PHITOT = .02
F23 = 2.5037	F12 = 9.6925	PN = .3310	PNPSI = .3310	DPHI2 = .1213E+07	PSIDOT = 26.12	PHITOT = .02
T = .00003	PHI = 139.02	PHIDOT = 30.60	G = .0222	PSID = 42.10	PSIDOT = .3316	PHITOT = .03
F23 = 2.5047	F12 = 9.6924	PN = .3316	PNPSI = .3316	DPHI2 = .1215E+07	PSIDOT = 31.30	PHITOT = .03
T = .00003	PHI = 139.03	PHIDOT = 36.67	G = .0221	PSID = 42.11	PSIDOT = .3318	PHITOT = .04
F23 = 2.5048	F12 = 9.6925	PN = .3318	PNPSI = .3318	DPHI2 = .1214E+07	PSIDOT = 36.50	PHITOT = .04
T = .00004	PHI = 139.04	PHIDOT = 42.74	G = .0221	PSID = 42.12	PSIDOT = .3326	PHITOT = .06
F23 = 2.5062	F12 = 9.6923	PN = .3326	PNPSI = .3326	DPHI2 = .1218E+07	PSIDOT = 41.71	PHITOT = .06
T = .00004	PHI = 139.06	PHIDOT = 48.82	G = .0220	PSID = 42.13	PSIDOT = .3328	PHITOT = .07
F23 = 2.5063	F12 = 9.6925	PN = .3328	PNPSI = .3328	DPHI2 = .1217E+07	PSIDOT = 46.93	PHITOT = .07
T = .00005	PHI = 139.07	PHIDOT = 54.91	G = .0220	PSID = 42.14	PSIDOT = .3339	PHITOT = .07
F23 = 2.5081	F12 = 9.6923	PN = .3339	PNPSI = .3339	DPHI2 = .1221E+07	PSIDOT = .3339	PHITOT = .07

T = .00005	PHI = 139.09	PHIDOT = 61.00	G = .0219	PSID = 42.16	PSIDOT = 52.16	PHITOT = .09
F23 = 2.5083	PHIDOT = 9.6926	PN = .3342	PNPSI = .3342	DPHI2 = .1220E+07		
T = .00005	PHI = 139.11	PHIDOT = 67.11	G = .0218	PSID = 42.17	PSIDOT = 57.41	PHITOT = .11
F23 = 2.5105	PHIDOT = 9.6924	PN = .3355	PNPSI = .3355	DPHI2 = .1225E+07		
T = .00006	PHI = 139.13	PHIDOT = 73.22	G = .0218	PSID = 42.19	PSIDOT = 62.68	PHITOT = .13
F23 = 2.5107	PHIDOT = 9.6926	PN = .3359	PNPSI = .3359	DPHI2 = .1224E+07		
T = .00006	PHI = 139.15	PHIDOT = 79.34	G = .0217	PSID = 42.21	PSIDOT = 67.96	PHITOT = .15
F23 = 2.5134	PHIDOT = 9.6924	PN = .3375	PNPSI = .3375	DPHI2 = .1230E+07		
T = .00007	PHI = 139.17	PHIDOT = 85.48	G = .0216	PSID = 42.23	PSIDOT = 73.26	PHITOT = .17
F23 = 2.5136	PHIDOT = 9.6927	PN = .3379	PNPSI = .3379	DPHI2 = .1228E+07		
T = .00007	PHI = 139.20	PHIDOT = 91.63	G = .0215	PSID = 42.25	PSIDOT = 78.59	PHITOT = .20
F23 = 2.5167	PHIDOT = 9.6925	PN = .3398	PNPSI = .3398	DPHI2 = .1235E+07		
T = .00008	PHI = 139.22	PHIDOT = 97.78	G = .0214	PSID = 42.27	PSIDOT = 83.94	PHITOT = .22
F23 = 2.5169	PHIDOT = 9.6929	PN = .3402	PNPSI = .3402	DPHI2 = .1233E+07		
T = .00008	PHI = 139.25	PHIDOT = 103.96	G = .0213	PSID = 42.30	PSIDOT = 89.31	PHITOT = .25
F23 = 2.5205	PHIDOT = 9.6925	PN = .3424	PNPSI = .3424	DPHI2 = .1242E+07		
T = .00009	PHI = 139.28	PHIDOT = 110.15	G = .0212	PSID = 42.32	PSIDOT = 94.71	PHITOT = .28
F23 = 2.5207	PHIDOT = 9.6930	PN = .3429	PNPSI = .3429	DPHI2 = .1239E+07		
T = .00009	PHI = 139.32	PHIDOT = 116.35	G = .0211	PSID = 42.35	PSIDOT = 100.14	PHITOT = .32
F23 = 2.5247	PHIDOT = 9.6927	PN = .3453	PNPSI = .3453	DPHI2 = .1248E+07		
T = .00010	PHI = 139.35	PHIDOT = 122.57	G = .0209	PSID = 42.38	PSIDOT = 105.59	PHITOT = .35
F23 = 2.5250	PHIDOT = 9.6932	PN = .3459	PNPSI = .3459	DPHI2 = .1246E+07		
T = .00011	PHI = 139.39	PHIDOT = 128.81	G = .0208	PSID = 42.41	PSIDOT = 111.09	PHITOT = .39
F23 = 2.5295	PHIDOT = 9.6928	PN = .3486	PNPSI = .3486	DPHI2 = .1256E+07		
T = .00011	PHI = 139.42	PHIDOT = 135.07	G = .0207	PSID = 42.45	PSIDOT = 116.60	PHITOT = .42
F23 = 2.5298	PHIDOT = 9.6934	PN = .3493	PNPSI = .3493	DPHI2 = .1253E+07		
T = .00012	PHI = 139.46	PHIDOT = 141.34	G = .0205	PSID = 42.48	PSIDOT = 122.17	PHITOT = .46
F23 = 2.5347	PHIDOT = 9.6930	PN = .3523	PNPSI = .3523	DPHI2 = .1264E+07		
T = .00012	PHI = 139.51	PHIDOT = 147.64	G = .0204	PSID = 42.52	PSIDOT = 127.76	PHITOT = .51
F23 = 2.5351	PHIDOT = 9.6936	PN = .3530	PNPSI = .3530	DPHI2 = .1261E+07		
T = .00013	PHI = 139.55	PHIDOT = 153.95	G = .0202	PSID = 42.55	PSIDOT = 133.39	PHITOT = .55
F23 = 2.5404	PHIDOT = 9.6932	PN = .3564	PNPSI = .3564	DPHI2 = .1273E+07		
T = .00013	PHI = 139.59	PHIDOT = 160.29	G = .0200	PSID = 42.59	PSIDOT = 139.06	PHITOT = .59
F23 = 2.5408	PHIDOT = 9.6939	PN = .3572	PNPSI = .3572	DPHI2 = .1269E+07		
T = .00014	PHI = 139.64	PHIDOT = 166.65	G = .0199	PSID = 42.63	PSIDOT = 144.78	PHITOT = .64
F23 = 2.5466	PHIDOT = 9.6935	PN = .3608	PNPSI = .3608	DPHI2 = .1282E+07		
T = .00014	PHI = 139.69	PHIDOT = 173.03	G = .0197	PSID = 42.67	PSIDOT = 150.53	PHITOT = .69
F23 = 2.5471	PHIDOT = 9.6943	PN = .3617	PNPSI = .3617	DPHI2 = .1278E+07		
T = .00015	PHI = 139.74	PHIDOT = 179.43	G = .0195	PSID = 42.72	PSIDOT = 156.34	PHITOT = .74
F23 = 2.5534	PHIDOT = 9.6938	PN = .3656	PNPSI = .3656	DPHI2 = .1292E+07		
T = .00015	PHI = 139.79	PHIDOT = 185.86	G = .0193	PSID = 42.76	PSIDOT = 162.19	PHITOT = .79
F23 = 2.5539	PHIDOT = 9.6947	PN = .3666	PNPSI = .3666	DPHI2 = .1288E+07		
T = .00015	PHI = 139.85	PHIDOT = 192.32	G = .0191	PSID = 42.81	PSIDOT = 168.09	PHITOT = .85
F23 = 2.5607	PHIDOT = 9.6942	PN = .3709	PNPSI = .3709	DPHI2 = .1303E+07		
T = .00016	PHI = 139.90	PHIDOT = 198.79	G = .0189	PSID = 42.86	PSIDOT = 174.04	PHITOT = .90
F23 = 2.5612	PHIDOT = 9.6951	PN = .3720	PNPSI = .3720	DPHI2 = .1298E+07		
T = .00016	PHI = 139.96	PHIDOT = 205.30	G = .0187	PSID = 42.91	PSIDOT = 180.05	PHITOT = .96
F23 = 2.5685	PHIDOT = 9.6946	PN = .3766	PNPSI = .3766	DPHI2 = .1314E+07		
T = .00017	PHI = 140.02	PHIDOT = 211.82	G = .0184	PSID = 42.96	PSIDOT = 186.11	PHITOT = 1.02
F23 = 2.5691	PHIDOT = 9.6957	PN = .3778	PNPSI = .3778	DPHI2 = .1309E+07		
T = .00017	PHI = 140.08	PHIDOT = 218.39	G = .0182	PSID = 43.02	PSIDOT = 192.23	PHITOT = 1.08
F23 = 2.3204	PHIDOT = 9.6984	PN = .3795	PNPSI = .3795	DPHI2 = .1306E+07		
T = .00018	PHI = 140.14	PHIDOT = 224.92	G = .0180	PSID = 43.07	PSIDOT = 198.37	PHITOT = 1.14
F23 = 2.3210	PHIDOT = 9.6995	PN = .3808	PNPSI = .3808	DPHI2 = .1301E+07		
T = .00018	PHI = 140.21	PHIDOT = 231.39	G = .0177	PSID = 43.13	PSIDOT = 204.48	PHITOT = 1.21
F23 = 2.3245	PHIDOT = 9.7052	PN = .3800	PNPSI = .3800	DPHI2 = .1282E+07		
T = .00019	PHI = 140.28	PHIDOT = 237.81	G = .0175	PSID = 43.19	PSIDOT = 210.58	PHITOT = 1.28
F23 = 2.3251	PHIDOT = 9.7064	PN = .3814	PNPSI = .3814	DPHI2 = .1276E+07		
T = .00019	PHI = 140.35	PHIDOT = 244.15	G = .0172	PSID = 43.25	PSIDOT = 216.65	PHITOT = 1.35
F23 = 2.3287	PHIDOT = 9.7123	PN = .3804	PNPSI = .3804	DPHI2 = .1256E+07		
T = .00020	PHI = 140.42	PHIDOT = 250.44	G = .0169	PSID = 43.32	PSIDOT = 222.72	PHITOT = 1.42

T = .00020	F23 = 2.3294	F12 = 9.7136	PN = .3819	PNPSI = .3819	DPH12 = .1250E+07
	PHI = 140.45	PHIDOT = 253.37	G = .0168	PSID = 43.35	PSIDOT = 225.57
T = .00020	F23 = 2.5807	F12 = 9.7315	PN = .3681	PNPSI = .3681	PHITOT = 1.45
	PHI = 140.49	PHIDOT = 256.26	G = .0167	PSID = 43.38	DPH12 = .1162E+07
T = .00021	F23 = 2.5812	F12 = 9.7322	PN = .3688	PNPSI = .3688	PSIDOT = 228.41
	PHI = 140.53	PHIDOT = 259.16	G = .0165	PSID = 43.41	DPH12 = .1159E+07
T = .00021	F23 = 2.5857	F12 = 9.7319	PN = .3718	PNPSI = .3718	PSIDOT = 231.26
	PHI = 140.56	PHIDOT = 262.07	G = .0164	PSID = 43.45	PHITOT = 1.53
T = .00021	F23 = 2.5861	F12 = 9.7326	PN = .3725	PNPSI = .3725	DPH12 = .1169E+07
	PHI = 140.60	PHIDOT = 264.99	G = .0163	PSID = 43.48	PSIDOT = 234.13
T = .00021	F23 = 2.5908	F12 = 9.7323	PN = .3756	PNPSI = .3756	PHITOT = 1.58
	PHI = 140.64	PHIDOT = 267.92	G = .0161	PSID = 43.51	DPH12 = .1166E+07
T = .00022	F23 = 2.5912	F12 = 9.7330	PN = .3763	PNPSI = .3763	PSIDOT = 237.02
	PHI = 140.68	PHIDOT = 270.85	G = .0160	PSID = 43.55	PHITOT = 1.60
T = .00022	F23 = 2.5961	F12 = 9.7327	PN = .3795	PNPSI = .3795	DPH12 = .1172E+07
	PHI = 140.72	PHIDOT = 273.79	G = .0158	PSID = 43.58	PSIDOT = 239.92
T = .00022	F23 = 2.5965	F12 = 9.7334	PN = .3803	PNPSI = .3803	PHITOT = 1.64
	PHI = 140.76	PHIDOT = 276.75	G = .0157	PSID = 43.62	DPH12 = .1179E+07
T = .00023	F23 = 2.6015	F12 = 9.7332	PN = .3835	PNPSI = .3835	PSIDOT = 242.85
	PHI = 140.80	PHIDOT = 279.70	G = .0155	PSID = 43.65	PHITOT = 1.68
T = .00023	F23 = 2.6019	F12 = 9.7339	PN = .3844	PNPSI = .3844	PSIDOT = 245.79
	PHI = 140.84	PHIDOT = 282.67	G = .0154	PSID = 43.69	PHITOT = 1.72
T = .00023	F23 = 2.6070	F12 = 9.7337	PN = .3877	PNPSI = .3877	DPH12 = .1182E+07
	PHI = 140.88	PHIDOT = 285.65	G = .0152	PSID = 43.72	PSIDOT = 248.75
T = .00023	F23 = 2.6075	F12 = 9.7344	PN = .3886	PNPSI = .3886	PHITOT = 1.76
	PHI = 140.92	PHIDOT = 288.63	G = .0151	PSID = 43.76	DPH12 = .1189E+07
T = .00023	F23 = 2.6127	F12 = 9.7342	PN = .3920	PNPSI = .3920	PSIDOT = 251.72
	PHI = 140.96	PHIDOT = 291.62	G = .0149	PSID = 43.80	PHITOT = 1.80
T = .00024	F23 = 2.6132	F12 = 9.7350	PN = .3929	PNPSI = .3929	DPH12 = .1185E+07
	PHI = 141.00	PHIDOT = 294.63	G = .0147	PSID = 43.84	PSIDOT = 254.72
T = .00024	F23 = 2.6185	F12 = 9.7347	PN = .3965	PNPSI = .3965	PHITOT = 1.84
	PHI = 141.04	PHIDOT = 297.63	G = .0146	PSID = 43.88	DPH12 = .1196E+07
T = .00024	F23 = 2.6190	F12 = 9.7355	PN = .3974	PNPSI = .3974	PSIDOT = 257.74
	PHI = 141.09	PHIDOT = 300.65	G = .0144	PSID = 43.92	PHITOT = 1.88
T = .00024	F23 = 2.6245	F12 = 9.7353	PN = .4010	PNPSI = .4010	DPH12 = .1192E+07
	PHI = 141.13	PHIDOT = 303.68	G = .0142	PSID = 43.96	PSIDOT = 260.77
T = .00025	F23 = 2.6250	F12 = 9.7362	PN = .4020	PNPSI = .4020	PHITOT = 1.92
	PHI = 141.17	PHIDOT = 306.71	G = .0141	PSID = 44.00	DPH12 = .1203E+07
T = .00025	F23 = 2.6306	F12 = 9.7359	PN = .4058	PNPSI = .4058	PSIDOT = 263.83
	PHI = 141.22	PHIDOT = 309.75	G = .0139	PSID = 44.04	PHITOT = 1.96
T = .00025	F23 = 2.6317	F12 = 9.7368	PN = .4068	PNPSI = .4068	DPH12 = .1199E+07
	PHI = 141.26	PHIDOT = 312.81	G = .0137	PSID = 44.08	PSIDOT = 266.90
T = .00026	F23 = 2.6369	F12 = 9.7366	PN = .4106	PNPSI = .4106	PHITOT = 2.00
	PHI = 141.31	PHIDOT = 315.86	G = .0136	PSID = 44.12	DPH12 = .1209E+07
T = .00026	F23 = 2.6374	F12 = 9.7375	PN = .4117	PNPSI = .4117	PSIDOT = 270.00
	PHI = 141.35	PHIDOT = 318.93	G = .0134	PSID = 44.16	PHITOT = 2.04
T = .00026	F23 = 2.6433	F12 = 9.7373	PN = .4157	PNPSI = .4157	DPH12 = .1205E+07
	PHI = 141.40	PHIDOT = 322.01	G = .0132	PSID = 44.20	PSIDOT = 273.12
T = .00026	F23 = 2.6439	F12 = 9.7382	PN = .4168	PNPSI = .4168	PHITOT = 2.09
	PHI = 141.45	PHIDOT = 325.09	G = .0130	PSID = 44.25	DPH12 = .1216E+07
T = .00026	F23 = 2.6861	F12 = 9.7413	PN = .4172	PNPSI = .4172	PSIDOT = 276.25
	PHI = 141.49	PHIDOT = 328.15	G = .0129	PSID = 44.29	PHITOT = 2.13
T = .00026	F23 = 2.6865	F12 = 9.7423	PN = .4184	PNPSI = .4184	DPH12 = .1212E+07
	PHI = 141.54	PHIDOT = 331.18	G = .0127	PSID = 44.33	PSIDOT = 279.41
T = .00027	F23 = 2.6891	F12 = 9.7465	PN = .4178	PNPSI = .4178	PHITOT = 2.17
	PHI = 141.59	PHIDOT = 334.19	G = .0125	PSID = 44.38	DPH12 = .1223E+07
T = .00027	F23 = 2.6896	F12 = 9.7475	PN = .4189	PNPSI = .4189	PSIDOT = 282.59
	PHI = 141.64	PHIDOT = 337.18	G = .0123	PSID = 44.42	PHITOT = 2.22
T = .00027	F23 = 2.6922	F12 = 9.7517	PN = .4183	PNPSI = .4183	DPH12 = .1219E+07
	PHI = 141.68	PHIDOT = 340.14	G = .0121	PSID = 44.47	PSIDOT = 285.79
T = .00027	F23 = 2.6927	F12 = 9.7528	PN = .4194	PNPSI = .4194	PHITOT = 2.26
	PHI = 141.73	PHIDOT = 343.15	G = .0119	PSID = 44.51	DPH12 = .1225E+07
T = .00027	F23 = 2.6932	F12 = 9.7539	PN = .4201	PNPSI = .4201	PSIDOT = 289.01
	PHI = 141.78	PHIDOT = 346.16	G = .0117	PSID = 44.55	PHITOT = 2.31
T = .00027	F23 = 2.6937	F12 = 9.7550	PN = .4212	PNPSI = .4212	DPH12 = .1230E+07
	PHI = 141.83	PHIDOT = 349.17	G = .0115	PSID = 44.59	PSIDOT = 292.26
T = .00027	F23 = 2.6942	F12 = 9.7561	PN = .4223	PNPSI = .4223	PHITOT = 2.35
	PHI = 141.88	PHIDOT = 352.18	G = .0113	PSID = 44.63	DPH12 = .1237E+07
T = .00027	F23 = 2.6947	F12 = 9.7572	PN = .4234	PNPSI = .4234	PSIDOT = 295.53
	PHI = 141.93	PHIDOT = 355.19	G = .0111	PSID = 44.67	PHITOT = 2.40
T = .00027	F23 = 2.6952	F12 = 9.7583	PN = .4245	PNPSI = .4245	DPH12 = .1232E+07
	PHI = 141.98	PHIDOT = 358.20	G = .0109	PSID = 44.71	PSIDOT = 298.81
T = .00027	F23 = 2.6957	F12 = 9.7594	PN = .4256	PNPSI = .4256	PHITOT = 2.45
	PHI = 142.03	PHIDOT = 361.21	G = .0107	PSID = 44.75	DPH12 = .1224E+07
T = .00027	F23 = 2.6962	F12 = 9.7605	PN = .4267	PNPSI = .4267	PSIDOT = 302.10
	PHI = 142.08	PHIDOT = 364.22	G = .0105	PSID = 44.79	PHITOT = 2.49
T = .00027	F23 = 2.6967	F12 = 9.7616	PN = .4278	PNPSI = .4278	DPH12 = .1219E+07
	PHI = 142.13	PHIDOT = 367.23	G = .0103	PSID = 44.83	PSIDOT = 305.37
T = .00027	F23 = 2.6972	F12 = 9.7627	PN = .4289	PNPSI = .4289	PHITOT = 2.54
	PHI = 142.18	PHIDOT = 370.24	G = .0101	PSID = 44.87	DPH12 = .1205E+07
T = .00027	F23 = 2.6977	F12 = 9.7638	PN = .4300	PNPSI = .4300	PSIDOT = 308.64
	PHI = 142.23	PHIDOT = 373.25	G = .0099	PSID = 44.91	PHITOT = 2.59
T = .00027	F23 = 2.6982	F12 = 9.7649	PN = .4311	PNPSI = .4311	DPH12 = .1200E+07
	PHI = 142.28	PHIDOT = 376.26	G = .0097	PSID = 44.95	PSIDOT = 311.91
T = .00027	F23 = 2.6987	F12 = 9.7660	PN = .4322	PNPSI = .4322	PHITOT = 2.64
	PHI = 142.33	PHIDOT = 379.27	G = .0095	PSID = 44.99	DPH12 = .1185E+07
T = .00027	F23 = 2.6992	F12 = 9.7671	PN = .4333	PNPSI = .4333	PSIDOT = 315.16
	PHI = 142.38	PHIDOT = 382.28	G = .0093	PSID = 45.03	PHITOT = 2.68
T = .00027	F23 = 2.6997	F12 = 9.7682	PN = .4344	PNPSI = .4344	DPH12 = .1180E+07
	PHI = 142.43	PHIDOT = 385.29	G = .0091	PSID = 45.07	PSIDOT = 318.17
T = .00027	F23 = 2.6999	F12 = 9.7693	PN = .4355	PNPSI = .4355	PHITOT = 2.73
	PHI = 142.48	PHIDOT = 388.30	G = .0089	PSID = 45.11	DPH12 = .1175E+07
T = .00027	F23 = 2.7004	F12 = 9.7704	PN = .4366	PNPSI = .4366	PSIDOT = 321.18
	PHI = 142.53	PHIDOT = 391.31	G = .0087	PSID = 45.15	PHITOT = 2.78
T = .00027	F23 = 2.7009	F12 = 9.7715	PN = .4377	PNPSI = .4377	DPH12 = .1170E+07
	PHI = 142.58	PHIDOT = 394.32	G = .0085	PSID = 45.19	PSIDOT = 324.19
T = .00027	F23 = 2.7014	F12 = 9.7726	PN = .4388	PNPSI = .4388	PHITOT = 2.83
	PHI = 142.63	PHIDOT = 397.33	G = .0083	PSID = 45.23	DPH12 = .1165E+07
T = .00027	F23 = 2.7019	F12 = 9.7737	PN = .4399	PNPSI = .4399	PSIDOT = 327.20
	PHI = 142.68	PHIDOT = 400.34	G = .0081	PSID = 45.27	PHITOT = 2.88
T = .00027	F23 = 2.7024	F12 = 9.7748	PN = .4410	PNPSI = .4410	DPH12 = .1160E+07
	PHI = 142.73	PHIDOT = 403.35	G = .0079	PSID = 45.31	PSIDOT = 330.21
T = .00027	F23 = 2.7029	F12 = 9.7759	PN = .4421	PNPSI = .4421	PHITOT = 2.93
	PHI = 142.78	PHIDOT = 406.36	G = .0077	PSID = 45.35	DPH12 = .1155E+07
T = .00027	F23 = 2.7034	F12 = 9.7770	PN = .4432	PNPSI = .4432	PSIDOT = 333.22
	PHI = 142.83	PHIDOT = 409.37	G = .0075	PSID = 45.39	PHITOT = 2.98
T = .00027	F23 = 2.7039	F12 = 9.7781	PN = .4443	PNPSI = .4443	DPH12 = .1150E+07
	PHI = 142.88	PHIDOT = 412.38	G = .0073	PSID = 45.43	PSIDOT = 336.23
T = .00027	F23 = 2.7044	F12 = 9.7792	PN = .4454	PNPSI = .4454	PHITOT = 3.03
	PHI = 142.93	PHIDOT = 415.39	G = .0071	PSID = 45.47	DPH12 = .1145E+07
T = .00027	F23 = 2.7049	F12 = 9.7803	PN = .4465	PNPSI = .4465	PSIDOT = 339.24
	PHI = 142.98	PHIDOT = 418.40	G = .0069	PSID = 45.51	PHITOT = 3.08
T = .00027	F23 = 2.7054	F12 = 9.7814	PN = .4476	PNPSI = .4476	DPH12 = .1140E+07
	PHI = 143.03	PHIDOT = 421.41	G = .0067	PSID = 45.55	PSIDOT = 342.25
T = .00027	F23 = 2.7059	F12 = 9.7825	PN = .4487	PNPSI = .4487	PHITOT = 3.13
	PHI = 143.08	PHIDOT = 424.42	G = .0065	PSID = 45.59	DPH12 = .1135E+07
T = .00027	F23 = 2.7064	F12 = 9.7836	PN = .4498	PNPSI = .4498	PSIDOT = 345.26
	PHI = 143.13	PHIDOT = 427.43	G = .0063	PSID = 45.63	PHITOT = 3.18
T = .00027	F23 = 2.7069	F12 = 9.7847	PN = .4509	PNPSI = .4509	DPH12 = .1130E+07
	PHI = 143.18	PHIDOT = 430.44	G = .0061	PSID = 45.67	PSIDOT = 348.27
T = .00027	F23 = 2.7074	F12 = 9.7858	PN = .4520	PNPSI = .4520	PHITOT = 3.23
	PHI = 143.23	PHIDOT = 433.45	G = .0059	PSID = 45.71	DPH12 = .1125E+07
T = .00027	F23 = 2.7079	F12 = 9.7869	PN = .4531	PNPSI = .4531	PSIDOT = 351.28
	PHI = 143.28	PHIDOT = 436.46	G = .0057	PSID = 45.75	PHITOT = 3.28
T = .00027	F23 = 2.7084	F12 = 9.7880	PN = .4542	PNPSI = .4542	DPH12 = .1120E+07
	PHI = 143.33	PHIDOT = 439.47	G = .0055	PSID = 45.79	PSIDOT = 354.29
T = .00027	F23 = 2.7089	F12 = 9.7891	PN = .4553	PNPSI = .4553	PHITOT = 3.33
	PHI = 143.38	PHIDOT = 442.48	G = .0053	PSID = 45.83	DPH12 = .1115E+07
T = .00027	F23 = 2.7094	F12 = 9.7902	PN = .4564	PNPSI = .4564	PSIDOT = 357.30
	PHI = 143.43	PHIDOT = 445.49	G = .0051	PSID = 45.87	PHITOT = 3.38
T = .00027	F23 = 2.7099	F12 = 9.7913	PN = .4575	PNPSI = .4575	DPH12 = .1110E+07
	PHI = 143.48	PHIDOT = 448.50	G = .0049	PSID = 45.91	PSIDOT = 360.31
T = .00027	F23 = 2.7104	F12 = 9.7924	PN = .4586	PNPSI = .4586	PHITOT = 3.43
	PHI = 143.53	PHIDOT = 451.51	G = .0047	PSID = 45.95	DPH12 = .1105E+07
T = .00027	F23 = 2.7109	F12 = 9.7935	PN = .4597	PNPSI = .4597	PSIDOT = 363.32
	PHI = 143.58	PHIDOT = 454.52	G = .0045	PSID = 45.99	PHITOT = 3.48
T = .00027	F23 = 2.7114	F12 = 9.7946	PN = .4608	PNPSI = .4608	DPH12 = .1100E+07
	PHI = 143.63	PHIDOT = 457.53	G = .0043	PSID = 46.03	PSIDOT = 366.33
T = .00027	F23 = 2.7119	F12 = 9.7957	PN = .4619	PNPSI = .4619	PHITOT = 3.53
	PHI = 143.68	PHIDOT = 460.54	G = .0041	PSID = 46.07	DPH12 = .1095E+07
T = .00027	F23 = 2.7124	F12 = 9.7968	PN = .4630	PNPSI = .4630	PSIDOT = 369.34
	PHI = 143.73	PHIDOT = 463.55	G = .0039	PSID = 46.11	PHITOT = 3.58
T = .00027	F23 = 2.7129	F12 = 9.7979	PN = .4641	PNPSI = .4641	DPH12 = .1090E+07

T = .00028	PHI = 141.73	PHIDOT = 343.08	G = .0120	PSID = 44.51	PSIDOT = 318.41	PHITOT = 2.73
F23 = 2.3953	F12 = 9.7571	PN = .4188	PNPSI = .4188	DPH12 = .1165E+07		
T = .00028	PHI = 141.78	PHIDOT = 345.99	G = .0118	PSID = 44.56	PSIDOT = 321.66	PHITOT = 2.78
F23 = 2.3958	F12 = 9.7581	PN = .4199	PNPSI = .4199	DPH12 = .1160E+07		
T = .00028	PHI = 141.83	PHIDOT = 348.68	G = .0116	PSID = 44.60	PSIDOT = 324.71	PHITOT = 2.83
F23 = 2.6506	F12 = 9.7759	PN = .4043	PNPSI = .4043	DPH12 = .1066E+07		
T = .00028	PHI = 141.88	PHIDOT = 351.33	G = .0114	PSID = 44.65	PSIDOT = 327.74	PHITOT = 2.88
F23 = 2.6512	F12 = 9.7769	PN = .4054	PNPSI = .4054	DPH12 = .1061E+07		
T = .00029	PHI = 141.93	PHIDOT = 353.99	G = .0112	PSID = 44.70	PSIDOT = 330.79	PHITOT = 2.93
F23 = 2.6578	F12 = 9.7768	PN = .4099	PNPSI = .4099	DPH12 = .1073E+07		
T = .00029	PHI = 141.98	PHIDOT = 356.65	G = .0110	PSID = 44.74	PSIDOT = 333.87	PHITOT = 2.98
F23 = 2.6583	F12 = 9.7779	PN = .4110	PNPSI = .4110	DPH12 = .1068E+07		
T = .00029	PHI = 142.04	PHIDOT = 359.33	G = .0108	PSID = 44.79	PSIDOT = 336.98	PHITOT = 3.04
F23 = 2.6651	F12 = 9.7777	PN = .4156	PNPSI = .4156	DPH12 = .1080E+07		
T = .00029	PHI = 142.09	PHIDOT = 362.01	G = .0106	PSID = 44.84	PSIDOT = 340.10	PHITOT = 3.09
F23 = 2.6657	F12 = 9.7788	PN = .4168	PNPSI = .4168	DPH12 = .1075E+07		
T = .00030	PHI = 142.14	PHIDOT = 364.70	G = .0104	PSID = 44.89	PSIDOT = 343.26	PHITOT = 3.14
F23 = 2.6725	F12 = 9.7787	PN = .4215	PNPSI = .4215	DPH12 = .1087E+07		
T = .00030	PHI = 142.19	PHIDOT = 367.40	G = .0102	PSID = 44.94	PSIDOT = 346.43	PHITOT = 3.19
F23 = 2.6732	F12 = 9.7798	PN = .4228	PNPSI = .4228	DPH12 = .1081E+07		
T = .00030	PHI = 142.24	PHIDOT = 370.11	G = .0100	PSID = 44.99	PSIDOT = 349.64	PHITOT = 3.24
F23 = 2.6801	F12 = 9.7797	PN = .4276	PNPSI = .4276	DPH12 = .1094E+07		
T = .00030	PHI = 142.30	PHIDOT = 372.82	G = .0098	PSID = 45.04	PSIDOT = 352.86	PHITOT = 3.30
F23 = 2.6808	F12 = 9.7809	PN = .4289	PNPSI = .4289	DPH12 = .1088E+07		
T = .00031	PHI = 142.35	PHIDOT = 375.55	G = .0096	PSID = 45.09	PSIDOT = 356.12	PHITOT = 3.35
F23 = 2.6879	F12 = 9.7808	PN = .4338	PNPSI = .4338	DPH12 = .1100E+07		
T = .00031	PHI = 142.40	PHIDOT = 378.28	G = .0094	PSID = 45.14	PSIDOT = 359.40	PHITOT = 3.40
F23 = 2.6886	F12 = 9.7820	PN = .4352	PNPSI = .4352	DPH12 = .1094E+07		
T = .00031	PHI = 142.46	PHIDOT = 381.02	G = .0092	PSID = 45.19	PSIDOT = 362.71	PHITOT = 3.46
F23 = 2.6958	F12 = 9.7820	PN = .4403	PNPSI = .4403	DPH12 = .1107E+07		
T = .00031	PHI = 142.51	PHIDOT = 383.76	G = .0089	PSID = 45.25	PSIDOT = 366.05	PHITOT = 3.51
F23 = 2.6965	F12 = 9.7832	PN = .4417	PNPSI = .4417	DPH12 = .1100E+07		
T = .00032	PHI = 142.57	PHIDOT = 386.52	G = .0087	PSID = 45.30	PSIDOT = 369.41	PHITOT = 3.57
F23 = 2.7039	F12 = 9.7832	PN = .4469	PNPSI = .4469	DPH12 = .1113E+07		
T = .00032	PHI = 142.62	PHIDOT = 389.28	G = .0086	PSID = 45.35	PSIDOT = 372.80	PHITOT = 3.62
F23 = 2.7047	F12 = 9.7845	PN = .4484	PNPSI = .4484	DPH12 = .1106E+07		
T = .00032	PHI = 142.68	PHIDOT = 392.05	G = .0083	PSID = 45.40	PSIDOT = 376.22	PHITOT = 3.68
F23 = 2.7122	F12 = 9.7845	PN = .4537	PNPSI = .4537	DPH12 = .1119E+07		
T = .00032	PHI = 142.74	PHIDOT = 394.83	G = .0081	PSID = 45.46	PSIDOT = 379.66	PHITOT = 3.74
F23 = 2.7130	F12 = 9.7858	PN = .4552	PNPSI = .4552	DPH12 = .1112E+07		
T = .00032	PHI = 142.79	PHIDOT = 397.61	G = .0079	PSID = 45.51	PSIDOT = 383.14	PHITOT = 3.79
F23 = 2.4523	F12 = 9.7856	PN = .4610	PNPSI = .4610	DPH12 = .1126E+07		
T = .00033	PHI = 142.85	PHIDOT = 400.40	G = .0076	PSID = 45.57	PSIDOT = 386.64	PHITOT = 3.85
F23 = 2.4530	F12 = 9.7870	PN = .4626	PNPSI = .4626	DPH12 = .1119E+07		
T = .00033	PHI = 142.91	PHIDOT = 403.18	G = .0074	PSID = 45.62	PSIDOT = 390.15	PHITOT = 3.91
F23 = 2.4562	F12 = 9.7923	PN = .4619	PNPSI = .4619	DPH12 = .1100E+07		
T = .00033	PHI = 142.97	PHIDOT = 405.93	G = .0072	PSID = 45.68	PSIDOT = 393.66	PHITOT = 3.97
F23 = 2.4569	F12 = 9.7937	PN = .4634	PNPSI = .4634	DPH12 = .1093E+07		
T = .00034	PHI = 143.02	PHIDOT = 408.64	G = .0070	PSID = 45.74	PSIDOT = 397.16	PHITOT = 4.02
F23 = 2.4601	F12 = 9.7990	PN = .4627	PNPSI = .4627	DPH12 = .1075E+07		
T = .00034	PHI = 143.08	PHIDOT = 411.33	G = .0067	PSID = 45.79	PSIDOT = 400.66	PHITOT = 4.08
F23 = 2.4608	F12 = 9.8005	PN = .4643	PNPSI = .4643	DPH12 = .1067E+07		
T = .00034	PHI = 143.14	PHIDOT = 413.98	G = .0065	PSID = 45.85	PSIDOT = 404.14	PHITOT = 4.14
F23 = 2.4640	F12 = 9.8059	PN = .4636	PNPSI = .4636	DPH12 = .1049E+07		
T = .00034	PHI = 143.20	PHIDOT = 416.60	G = .0063	PSID = 45.91	PSIDOT = 407.62	PHITOT = 4.20
F23 = 2.4648	F12 = 9.8074	PN = .4652	PNPSI = .4652	DPH12 = .1041E+07		
T = .00035	PHI = 143.23	PHIDOT = 417.80	G = .0062	PSID = 45.94	PSIDOT = 409.26	PHITOT = 4.23
F23 = 2.7282	F12 = 9.8250	PN = .4482	PNPSI = .4482	DPH12 = .9531E+06		
T = .00035	PHI = 143.26	PHIDOT = 418.99	G = .0060	PSID = 45.97	PSIDOT = 410.89	PHITOT = 4.28
F23 = 2.7286	F12 = 9.8257	PN = .4489	PNPSI = .4489	DPH12 = .9495E+06		
T = .00035	PHI = 143.29	PHIDOT = 420.18	G = .0059	PSID = 46.00	PSIDOT = 412.53	PHITOT = 4.29

T = .00035	F23 = 2.7326	F12 = 9.8258	PN = .4519	PNPSI = .4519	PSID = .4519	DPH12 = .9558E+06	PHITOT = 4.32
	PHI = 143.32	EHIDOT = 421.37	G = .0058	PNPSI = .4527	PSID = .4527	DPH12 = .9521E+06	
T = .00035	F23 = 2.7330	F12 = 9.8265	PN = .4527	PNPSI = .4527	PSID = .4527	DPH12 = .9521E+06	PHITOT = 4.35
	PHI = 143.35	PHIDOT = 422.56	G = .0057	PNPSI = .4556	PSID = .4556	DPH12 = .9585E+06	
T = .00035	F23 = 2.7371	F12 = 9.8265	PN = .4556	PNPSI = .4556	PSID = .4556	DPH12 = .9585E+06	PHITOT = 4.38
	PHI = 143.38	PHIDOT = 423.75	G = .0056	PNPSI = .4564	PSID = .4564	DPH12 = .9547E+06	
T = .00035	F23 = 2.7376	F12 = 9.8273	PN = .4564	PNPSI = .4564	PSID = .4564	DPH12 = .9547E+06	PHITOT = 4.41
	PHI = 143.41	PHIDOT = 424.95	G = .0054	PNPSI = .4594	PSID = .4594	DPH12 = .9611E+06	
T = .00035	F23 = 2.7417	F12 = 9.8274	PN = .4594	PNPSI = .4594	PSID = .4594	DPH12 = .9611E+06	PHITOT = 4.44
	PHI = 143.44	PHIDOT = 426.14	G = .0053	PNPSI = .4602	PSID = .4602	DPH12 = .9573E+06	
T = .00036	F23 = 2.7421	F12 = 9.8281	PN = .4602	PNPSI = .4602	PSID = .4602	DPH12 = .9573E+06	PHITOT = 4.47
	PHI = 143.47	PHIDOT = 427.34	G = .0052	PNPSI = .4618	PSID = .4618	DPH12 = .9636E+06	
T = .00036	F23 = 2.7463	F12 = 9.8282	PN = .4633	PNPSI = .4633	PSID = .4633	DPH12 = .9636E+06	PHITOT = 4.50
	PHI = 143.50	PHIDOT = 428.54	G = .0051	PNPSI = .4621	PSID = .4621	DPH12 = .9597E+06	
T = .00036	F23 = 2.7467	F12 = 9.8289	PN = .4641	PNPSI = .4641	PSID = .4641	DPH12 = .9597E+06	PHITOT = 4.54
	PHI = 143.54	PHIDOT = 429.74	G = .0050	PNPSI = .4672	PSID = .4672	DPH12 = .9660E+06	
T = .00036	F23 = 2.7509	F12 = 9.8290	PN = .4672	PNPSI = .4672	PSID = .4672	DPH12 = .9660E+06	PHITOT = 4.57
	PHI = 143.57	PHIDOT = 430.94	G = .0048	PNPSI = .4681	PSID = .4681	DPH12 = .9621E+06	
T = .00036	F23 = 2.7514	F12 = 9.8298	PN = .4681	PNPSI = .4681	PSID = .4681	DPH12 = .9621E+06	PHITOT = 4.60
	PHI = 143.60	PHIDOT = 432.14	G = .0047	PNPSI = .4630	PSID = .4630	DPH12 = .9684E+06	
T = .00036	F23 = 2.7556	F12 = 9.8299	PN = .4712	PNPSI = .4712	PSID = .4712	DPH12 = .9684E+06	PHITOT = 4.63
	PHI = 143.63	PHIDOT = 433.35	G = .0046	PNPSI = .4720	PSID = .4720	DPH12 = .9644E+06	
T = .00036	F23 = 2.7561	F12 = 9.8307	PN = .4720	PNPSI = .4720	PSID = .4720	DPH12 = .9644E+06	PHITOT = 4.66
	PHI = 143.66	PHIDOT = 434.55	G = .0045	PNPSI = .4752	PSID = .4752	DPH12 = .9707E+06	
T = .00036	F23 = 2.7604	F12 = 9.8308	PN = .4752	PNPSI = .4752	PSID = .4752	DPH12 = .9707E+06	PHITOT = 4.69
	PHI = 143.69	PHIDOT = 435.76	G = .0044	PNPSI = .4761	PSID = .4761	DPH12 = .9666E+06	
T = .00037	F23 = 2.7608	F12 = 9.8316	PN = .4761	PNPSI = .4761	PSID = .4761	DPH12 = .9666E+06	PHITOT = 4.72
	PHI = 143.72	PHIDOT = 436.97	G = .0042	PNPSI = .4793	PSID = .4793	DPH12 = .9729E+06	
T = .00037	F23 = 2.7651	F12 = 9.8317	PN = .4793	PNPSI = .4793	PSID = .4793	DPH12 = .9729E+06	PHITOT = 4.75
	PHI = 143.75	PHIDOT = 438.18	G = .0041	PNPSI = .4802	PSID = .4802	DPH12 = .9687E+06	
T = .00037	F23 = 2.7656	F12 = 9.8325	PN = .4802	PNPSI = .4802	PSID = .4802	DPH12 = .9687E+06	PHITOT = 4.78
	PHI = 143.78	PHIDOT = 439.39	G = .0040	PNPSI = .4824	PSID = .4824	DPH12 = .9705E+06	
T = .00037	F23 = 2.7637	F12 = 9.8306	PN = .4824	PNPSI = .4824	PSID = .4824	DPH12 = .9705E+06	PHITOT = 4.82
	PHI = 143.82	PHIDOT = 440.60	G = .0039	PNPSI = .4833	PSID = .4833	DPH12 = .9663E+06	
T = .00037	F23 = 2.7642	F12 = 9.8313	PN = .4833	PNPSI = .4833	PSID = .4833	DPH12 = .9663E+06	PHITOT = 4.85
	PHI = 143.85	PHIDOT = 441.81	G = .0037	PNPSI = .4858	PSID = .4858	DPH12 = .9689E+06	
T = .00037	F23 = 2.7636	F12 = 9.8301	PN = .4858	PNPSI = .4858	PSID = .4858	DPH12 = .9689E+06	PHITOT = 4.88
	PHI = 143.88	PHIDOT = 443.01	G = .0038	PNPSI = .4868	PSID = .4868	DPH12 = .9646E+06	
T = .00037	F23 = 2.7641	F12 = 9.8308	PN = .4868	PNPSI = .4868	PSID = .4868	DPH12 = .9646E+06	PHITOT = 4.91
	PHI = 143.91	PHIDOT = 444.22	G = .0035	PNPSI = .4893	PSID = .4893	DPH12 = .9672E+06	
T = .00037	F23 = 2.7835	F12 = 9.8796	PN = .4893	PNPSI = .4893	PSID = .4893	DPH12 = .9672E+06	PHITOT = 4.94
	PHI = 143.94	PHIDOT = 445.42	G = .0034	PNPSI = .4902	PSID = .4902	DPH12 = .9629E+06	
T = .00038	F23 = 2.7640	F12 = 9.8304	PN = .4902	PNPSI = .4902	PSID = .4902	DPH12 = .9629E+06	PHITOT = 4.97
	PHI = 143.97	PHIDOT = 446.62	G = .0032	PNPSI = .4928	PSID = .4928	DPH12 = .9654E+06	
T = .00038	F23 = 2.7634	F12 = 9.8791	PN = .4928	PNPSI = .4928	PSID = .4928	DPH12 = .9654E+06	PHITOT = 5.01
	PHI = 144.01	PHIDOT = 447.83	G = .0031	PNPSI = .4937	PSID = .4937	DPH12 = .9610E+06	
T = .00038	F23 = 2.7639	F12 = 9.8799	PN = .4937	PNPSI = .4937	PSID = .4937	DPH12 = .9610E+06	PHITOT = 5.04
	PHI = 144.04	PHIDOT = 449.03	G = .0030	PNPSI = .4963	PSID = .4963	DPH12 = .9635E+06	
T = .00038	F23 = 2.7633	F12 = 9.8787	PN = .4963	PNPSI = .4963	PSID = .4963	DPH12 = .9635E+06	PHITOT = 5.07
	PHI = 144.07	PHIDOT = 450.23	G = .0028	PNPSI = .4973	PSID = .4973	DPH12 = .9590E+06	
T = .00038	F23 = 2.7638	F12 = 9.8795	PN = .4973	PNPSI = .4973	PSID = .4973	DPH12 = .9590E+06	PHITOT = 5.10
	PHI = 144.10	PHIDOT = 451.42	G = .0027	PNPSI = .4981	PSID = .4981	DPH12 = .9614E+06	
T = .00038	F23 = 2.7632	F12 = 9.8782	PN = .4981	PNPSI = .4981	PSID = .4981	DPH12 = .9614E+06	PHITOT = 5.14
	PHI = 144.14	PHIDOT = 452.62	G = .0026	PNPSI = .5009	PSID = .5009	DPH12 = .9568E+06	
T = .00038	F23 = 2.7638	F12 = 9.8790	PN = .5009	PNPSI = .5009	PSID = .5009	DPH12 = .9568E+06	PHITOT = 5.17
	PHI = 144.17	PHIDOT = 453.82	G = .0025	PNPSI = .5035	PSID = .5035	DPH12 = .9592E+06	
T = .00038	F23 = 2.7632	F12 = 9.8778	PN = .5035	PNPSI = .5035	PSID = .5035	DPH12 = .9592E+06	PHITOT = 5.20
	PHI = 144.20	PHIDOT = 455.01	G = .0023	PNPSI = .5045	PSID = .5045	DPH12 = .9546E+06	
T = .00039	F23 = 2.7637	F12 = 9.8786	PN = .5045	PNPSI = .5045	PSID = .5045	DPH12 = .9546E+06	PHITOT = 5.23
	PHI = 144.23	PHIDOT = 456.20	G = .0022	PNPSI = .5041	PSID = .5041	DPH12 = .9438E+06	
T = .00039	F23 = 2.4887	F12 = 9.8794	PN = .5041	PNPSI = .5041	PSID = .5041	DPH12 = .9438E+06	PHITOT = 5.23

T = .00039	PHI = 144.27	PHIDOT = 457.38	G = .0021	PSID = 46.97	PSIDOT = 466.80	PHITOT = 5.27
	F23 = 2.4891	F12 = 8.9802	PN = .5051	PNPSI = .5051	DPH12 = .9391E+06	
T = .00039	PHI = 144.30	PHIDOT = 458.55	G = .0019	PSID = 47.01	PSIDOT = 468.63	PHITOT = 5.30
	F23 = 2.4863	F12 = 8.9816	PN = .5039	PNPSI = .5039	DPH12 = .9247E+06	
T = .00039	PHI = 144.33	PHIDOT = 459.70	G = .0018	PSID = 47.04	PSIDOT = 470.45	PHITOT = 5.33
	F23 = 2.4867	F12 = 8.9824	PN = .5050	PNPSI = .5050	DPH12 = .9200E+06	
T = .00039	PHI = 144.36	PHIDOT = 460.85	G = .0017	PSID = 47.07	PSIDOT = 472.27	PHITOT = 5.36
	F23 = 2.4839	F12 = 8.9838	PN = .5037	PNPSI = .5037	DPH12 = .9055E+06	
T = .00039	PHI = 144.40	PHIDOT = 461.98	G = .0015	PSID = 47.11	PSIDOT = 474.08	PHITOT = 5.40
	F23 = 2.4843	F12 = 8.9847	PN = .5048	PNPSI = .5048	DPH12 = .9008E+06	
T = .00039	PHI = 144.43	PHIDOT = 463.10	G = .0014	PSID = 47.14	PSIDOT = 475.89	PHITOT = 5.43
	F23 = 2.4814	F12 = 8.9860	PN = .5035	PNPSI = .5035	DPH12 = .8863E+06	
T = .00039	PHI = 144.46	PHIDOT = 464.21	G = .0013	PSID = 47.18	PSIDOT = 477.70	PHITOT = 5.46
	F23 = 2.4819	F12 = 8.9869	PN = .5045	PNPSI = .5045	DPH12 = .8815E+06	
T = .00040	PHI = 144.50	PHIDOT = 465.30	G = .0012	PSID = 47.21	PSIDOT = 479.49	PHITOT = 5.50
	F23 = 2.4790	F12 = 8.9882	PN = .5033	PNPSI = .5033	DPH12 = .8670E+06	
T = .00040	PHI = 144.53	PHIDOT = 466.39	G = .0010	PSID = 47.24	PSIDOT = 481.29	PHITOT = 5.53
	F23 = 2.4755	F12 = 8.9891	PN = .5043	PNPSI = .5043	DPH12 = .8622E+06	
T = .00040	PHI = 144.56	PHIDOT = 467.34	G = .0009	PSID = 47.28	PSIDOT = 482.95	PHITOT = 5.56
	F23 = 2.5664	F12 = 9.8047	PN = .4552	PNPSI = .4552	DPH12 = .8465E+06	
T = .00040	PHI = 144.60	PHIDOT = 468.24	G = .0008	PSID = 47.31	PSIDOT = 484.57	PHITOT = 5.60
	F23 = 2.5669	F12 = 9.8056	PN = .4561	PNPSI = .4561	DPH12 = .8422E+06	
T = .00040	PHI = 144.63	PHIDOT = 469.04	G = .0006	PSID = 47.35	PSIDOT = 486.09	PHITOT = 5.63
	F23 = 2.5714	F12 = 9.8059	PN = .4594	PNPSI = .4594	DPH12 = .8479E+06	
T = .00040	PHI = 144.67	PHIDOT = 469.84	G = .0005	PSID = 47.38	PSIDOT = 487.63	PHITOT = 5.67
	F23 = 2.5719	F12 = 9.8067	PN = .4603	PNPSI = .4603	DPH12 = .8438E+06	
T = .00040	PHI = 144.70	PHIDOT = 470.65	G = .0003	PSID = 47.42	PSIDOT = 489.17	PHITOT = 5.70
	F23 = 2.5764	F12 = 9.8070	PN = .4637	PNPSI = .4637	DPH12 = .8493E+06	
T = .00040	PHI = 144.73	PHIDOT = 471.45	G = .0002	PSID = 47.45	PSIDOT = 490.71	PHITOT = 5.73
	F23 = 2.5769	F12 = 9.8079	PN = .4646	PNPSI = .4646	DPH12 = .8449E+06	
T = .00041	PHI = 144.77	PHIDOT = 472.26	G = .0001	PSID = 47.49	PSIDOT = 492.27	PHITOT = 5.77
	F23 = 2.5815	F12 = 9.8082	PN = .4680	PNPSI = .4680	DPH12 = .8505E+06	
T = .00041	PHI = 144.80	PHIDOT = 473.07	G = .0001	PSID = 47.52	PSIDOT = 493.83	PHITOT = 5.80
	F23 = 2.5820	F12 = 9.8091	PN = .4689	PNPSI = .4689	DPH12 = .8461E+06	

FREE MOTION

T = .00041	PHI = 210.25	PHIDOT = 473.07	PSI = 314.59	PSIDOT = 493.93	PHITOT = 5.80
	FF12 = 9.439	FF23 = 2.359			
T = .00041	PHI = 210.32	PHIDOT = 480.50	PSI = 314.66	PSIDOT = 491.92	PHITOT = 5.87
	FF12 = 9.414	FF23 = 2.390			
T = .00041	PHI = 210.39	PHIDOT = 488.17	PSI = 314.74	PSIDOT = 490.02	PHITOT = 5.94
	FF12 = 9.419	FF23 = 2.390			
T = .00041	PHI = 210.46	PHIDOT = 495.84	PSI = 314.81	PSIDOT = 488.11	PHITOT = 6.01
	FF12 = 9.412	FF23 = 2.159			
T = .00042	PHI = 210.53	PHIDOT = 503.55	PSI = 314.88	PSIDOT = 486.20	PHITOT = 6.08
	FF12 = 9.412	FF23 = 2.160			
T = .00042	PHI = 210.61	PHIDOT = 511.24	PSI = 314.94	PSIDOT = 484.29	PHITOT = 6.15
	FF12 = 9.419	FF23 = 2.164			
T = .00042	PHI = 210.68	PHIDOT = 518.91	PSI = 315.01	PSIDOT = 482.39	PHITOT = 6.23
	FF12 = 9.419	FF23 = 2.164			
T = .00042	PHI = 210.76	PHIDOT = 526.55	PSI = 315.08	PSIDOT = 480.48	PHITOT = 6.30
	FF12 = 9.426	FF23 = 2.168			
T = .00043	PHI = 210.83	PHIDOT = 534.16	PSI = 315.15	PSIDOT = 478.57	PHITOT = 6.38
	FF12 = 9.426	FF23 = 2.168			
T = .00043	PHI = 210.87	PHIDOT = 537.79	PSI = 315.19	PSIDOT = 477.62	PHITOT = 6.42
	FF12 = 9.454	FF23 = 2.409			
T = .00043	PHI = 210.91	PHIDOT = 541.40	PSI = 315.22	PSIDOT = 475.66	PHITOT = 6.45
	FF12 = 9.454	FF23 = 2.409			
T = .00043	PHI = 210.95	PHIDOT = 545.03	PSI = 315.25	PSIDOT = 473.71	PHITOT = 6.49

T = .00043	FF12 = 9.451	FF23 = 2.412	PHI = 210.99	PHIDOT = 548.67	PSI = 315.29	PSIDOT = 474.76	PHITOT = 6.53
T = .00043	FF12 = 9.451	FF23 = 2.412	PHI = 211.03	PHIDOT = 552.33	PSI = 315.32	PSIDOT = 473.80	PHITOT = 6.57
T = .00043	FF12 = 9.449	FF23 = 2.416	PHI = 211.07	PHIDOT = 556.00	PSI = 315.36	PSIDOT = 472.85	PHITOT = 6.61
T = .00044	FF12 = 9.449	FF23 = 2.416	PHI = 211.11	PHIDOT = 559.69	PSI = 315.39	PSIDOT = 471.90	PHITOT = 6.65
T = .00044	FF12 = 9.446	FF23 = 2.419	PHI = 211.15	PHIDOT = 563.38	PSI = 315.42	PSIDOT = 470.94	PHITOT = 6.69
T = .00044	FF12 = 9.446	FF23 = 2.412	PHI = 211.19	PHIDOT = 567.10	PSI = 315.46	PSIDOT = 469.99	PHITOT = 6.73
T = .00044	FF12 = 9.444	FF23 = 2.422	PHI = 211.23	PHIDOT = 570.83	PSI = 315.49	PSIDOT = 469.04	PHITOT = 6.77
T = .00044	FF12 = 9.444	FF23 = 2.422	PHI = 211.27	PHIDOT = 574.58	PSI = 315.52	PSIDOT = 468.08	PHITOT = 6.81
T = .00044	FF12 = 9.441	FF23 = 2.426	PHI = 211.31	PHIDOT = 578.34	PSI = 315.56	PSIDOT = 467.13	PHITOT = 6.86
T = .00044	FF12 = 9.438	FF23 = 2.429	PHI = 211.35	PHIDOT = 582.12	PSI = 315.59	PSIDOT = 466.18	PHITOT = 6.90
T = .00044	FF12 = 9.439	FF23 = 2.429	PHI = 211.39	PHIDOT = 585.91	PSI = 315.62	PSIDOT = 465.22	PHITOT = 6.94
T = .00045	FF12 = 9.436	FF23 = 2.433	PHI = 211.44	PHIDOT = 589.72	PSI = 315.66	PSIDOT = 464.27	PHITOT = 6.98
T = .00045	FF12 = 9.436	FF23 = 2.433	PHI = 211.48	PHIDOT = 593.54	PSI = 315.69	PSIDOT = 463.31	PHITOT = 7.02
T = .00045	FF12 = 9.433	FF23 = 2.437	PHI = 211.52	PHIDOT = 597.38	PSI = 315.72	PSIDOT = 462.36	PHITOT = 7.07
T = .00045	FF12 = 9.433	FF23 = 2.437	PHI = 211.56	PHIDOT = 601.24	PSI = 315.76	PSIDOT = 461.41	PHITOT = 7.11
T = .00045	FF12 = 9.430	FF23 = 2.440	PHI = 211.61	PHIDOT = 605.11	PSI = 315.79	PSIDOT = 460.45	PHITOT = 7.15
T = .00045	FF12 = 9.430	FF23 = 2.440	PHI = 211.65	PHIDOT = 609.00	PSI = 315.82	PSIDOT = 459.50	PHITOT = 7.20
T = .00045	FF12 = 9.427	FF23 = 2.444	PHI = 211.69	PHIDOT = 612.91	PSI = 315.86	PSIDOT = 458.55	PHITOT = 7.24
T = .00045	FF12 = 9.427	FF23 = 2.444	PHI = 211.74	PHIDOT = 616.83	PSI = 315.89	PSIDOT = 457.59	PHITOT = 7.28
T = .00046	FF12 = 9.428	FF23 = 2.444	PHI = 211.78	PHIDOT = 620.77	PSI = 315.92	PSIDOT = 456.64	PHITOT = 7.33
VP = 47.109	VS = -71.706						
IMPACT							
VP = 13.152	VS = 13.152		PHI = 211.782	PHIDOT = 113.856	PSI = 315.922	PSIDOT = -127.482	PHITOT = 7.327

COUPLED MOTION

T = .00046	PHI = 211.78	PHIDOT = 113.86	G = .0115	PSID = 315.90	PSIDOT = -127.59	PHITOT = 7.33
F23 = 2.4000	F12 = 9.7741	PN = .3925	PNPSI = .3925	DPH12 = .1124E+07		
T = .00047	PHI = 211.85	PHIDOT = 125.13	G = .0113	PSID = 315.82	PSIDOT = -139.53	PHITOT = 7.40
F23 = 2.4015	F12 = 9.7764	PN = .3882	PNPSI = .3882	DPH12 = .1126E+07		
T = .00048	PHI = 211.93	PHIDOT = 136.50	G = .0111	PSID = 315.74	PSIDOT = -151.39	PHITOT = 7.47
F23 = 2.4002	F12 = 9.7742	PN = .3863	PNPSI = .3863	DPH12 = .1141E+07		
T = .00049	PHI = 212.01	PHIDOT = 147.94	G = .0106	PSID = 315.65	PSIDOT = -163.12	PHITOT = 7.55
F23 = 2.4021	F12 = 9.7769	PN = .3812	PNPSI = .3812	DPH12 = .1142E+07		
T = .00050	PHI = 212.09	PHIDOT = 159.49	G = .0105	PSID = 315.55	PSIDOT = -174.74	PHITOT = 7.64
F23 = 2.4006	F12 = 9.7743	PN = .3790	PNPSI = .3790	DPH12 = .1159E+07		
T = .00050	PHI = 212.14	PHIDOT = 164.97	G = .0103	PSID = 315.50	PSIDOT = -180.14	PHITOT = 7.69
F23 = 2.6589	F12 = 9.7892	PN = .3619	PNPSI = .3619	DPH12 = .1095E+07		

T = .00051	PHI = 212.19	PHIDOT = 170.45	G = -.0102	PSID = 315.45	PSIDOT = -185.48	PHITOT = 7.73
	F23 = 2.6580	F12 = 9.7878	PN = .3607	PNPSI = .3607	DPH12 = .1105E+07	
T = .00051	PHI = 212.24	PHIDOT = 176.02	G = -.0100	PSID = 315.39	PSIDOT = -190.86	PHITOT = 7.78
	F23 = 2.6633	F12 = 9.7856	PN = .3629	PNPSI = .3629	DPH12 = .1129E+07	
T = .00052	PHI = 212.29	PHIDOT = 181.67	G = -.0098	PSID = 315.34	PSIDOT = -196.26	PHITOT = 7.84
	F23 = 2.6623	F12 = 9.7841	PN = .3617	PNPSI = .3617	DPH12 = .1138E+07	
T = .00052	PHI = 212.34	PHIDOT = 187.41	G = -.0096	PSID = 315.28	PSIDOT = -201.69	PHITOT = 7.89
	F23 = 2.6679	F12 = 9.7817	PN = .3640	PNPSI = .3640	DPH12 = .1165E+07	
T = .00053	PHI = 212.40	PHIDOT = 193.23	G = -.0095	PSID = 315.22	PSIDOT = -207.14	PHITOT = 7.94
	F23 = 2.6669	F12 = 9.7801	PN = .3626	PNPSI = .3626	DPH12 = .1175E+07	
T = .00053	PHI = 212.45	PHIDOT = 199.16	G = -.0093	PSID = 315.16	PSIDOT = -212.63	PHITOT = 8.00
	F23 = 2.6728	F12 = 9.7775	PN = .3650	PNPSI = .3650	DPH12 = .1203E+07	
T = .00054	PHI = 212.51	PHIDOT = 205.17	G = -.0091	PSID = 315.10	PSIDOT = -218.14	PHITOT = 8.06
	F23 = 2.6717	F12 = 9.7757	PN = .3636	PNPSI = .3636	DPH12 = .1214E+07	
T = .00054	PHI = 212.57	PHIDOT = 211.30	G = -.0089	PSID = 315.04	PSIDOT = -223.68	PHITOT = 8.12
	F23 = 2.6779	F12 = 9.7729	PN = .3660	PNPSI = .3660	DPH12 = .1244E+07	
T = .00055	PHI = 212.63	PHIDOT = 217.52	G = -.0087	PSID = 314.97	PSIDOT = -229.25	PHITOT = 8.18
	F23 = 2.6767	F12 = 9.7710	PN = .3644	PNPSI = .3644	DPH12 = .1256E+07	
T = .00055	PHI = 212.70	PHIDOT = 223.86	G = -.0085	PSID = 314.91	PSIDOT = -234.86	PHITOT = 8.24
	F23 = 2.6832	F12 = 9.7679	PN = .3670	PNPSI = .3670	DPH12 = .1288E+07	
T = .00056	PHI = 212.76	PHIDOT = 230.30	G = -.0082	PSID = 314.84	PSIDOT = -240.49	PHITOT = 8.31
	F23 = 2.6819	F12 = 9.7659	PN = .3653	PNPSI = .3653	DPH12 = .1301E+07	
T = .00056	PHI = 212.83	PHIDOT = 236.88	G = -.0080	PSID = 314.77	PSIDOT = -246.16	PHITOT = 8.37
	F23 = 2.6888	F12 = 9.7625	PN = .3679	PNPSI = .3679	DPH12 = .1336E+07	
T = .00057	PHI = 212.90	PHIDOT = 243.56	G = -.0078	PSID = 314.70	PSIDOT = -251.85	PHITOT = 8.44
	F23 = 2.6874	F12 = 9.7603	PN = .3661	PNPSI = .3661	DPH12 = .1350E+07	
T = .00057	PHI = 212.97	PHIDOT = 250.38	G = -.0075	PSID = 314.63	PSIDOT = -257.58	PHITOT = 8.51
	F23 = 2.6947	F12 = 9.7566	PN = .3688	PNPSI = .3688	DPH12 = .1388E+07	
T = .00058	PHI = 213.04	PHIDOT = 257.32	G = -.0073	PSID = 314.55	PSIDOT = -263.33	PHITOT = 8.58
	F23 = 2.6932	F12 = 9.7543	PN = .3667	PNPSI = .3667	DPH12 = .1402E+07	
T = .00058	PHI = 213.11	PHIDOT = 264.41	G = -.0070	PSID = 314.47	PSIDOT = -269.13	PHITOT = 8.66
	F23 = 2.4310	F12 = 9.7544	PN = .3647	PNPSI = .3647	DPH12 = .1419E+07	
T = .00059	PHI = 213.19	PHIDOT = 271.56	G = -.0068	PSID = 314.40	PSIDOT = -274.88	PHITOT = 8.74
	F23 = 2.4296	F12 = 9.7519	PN = .3625	PNPSI = .3625	DPH12 = .1434E+07	
T = .00059	PHI = 213.27	PHIDOT = 278.75	G = -.0065	PSID = 314.32	PSIDOT = -280.55	PHITOT = 8.82
	F23 = 2.4314	F12 = 9.7546	PN = .3573	PNPSI = .3573	DPH12 = .1436E+07	
T = .00060	PHI = 213.35	PHIDOT = 285.99	G = -.0062	PSID = 314.24	PSIDOT = -286.16	PHITOT = 8.90
	F23 = 2.4299	F12 = 9.7521	PN = .3549	PNPSI = .3549	DPH12 = .1452E+07	
T = .00060	PHI = 213.37	PHIDOT = 287.71	G = -.0062	PSID = 314.22	PSIDOT = -287.45	PHITOT = 8.92
	F23 = 2.6899	F12 = 9.7713	PN = .3359	PNPSI = .3359	DPH12 = .1362E+07	
T = .00060	PHI = 213.39	PHIDOT = 289.41	G = -.0061	PSID = 314.19	PSIDOT = -288.72	PHITOT = 8.94
	F23 = 2.6895	F12 = 9.7707	PN = .3353	PNPSI = .3353	DPH12 = .1366E+07	
T = .00060	PHI = 213.41	PHIDOT = 291.12	G = -.0060	PSID = 314.17	PSIDOT = -289.99	PHITOT = 8.96
	F23 = 2.6916	F12 = 9.7696	PN = .3361	PNPSI = .3361	DPH12 = .1377E+07	
T = .00060	PHI = 213.43	PHIDOT = 292.85	G = -.0060	PSID = 314.15	PSIDOT = -291.26	PHITOT = 8.98
	F23 = 2.6912	F12 = 9.7690	PN = .3355	PNPSI = .3355	DPH12 = .1381E+07	
T = .00060	PHI = 213.46	PHIDOT = 294.68	G = -.0059	PSID = 314.13	PSIDOT = -292.54	PHITOT = 9.00
	F23 = 2.6933	F12 = 9.7679	PN = .3363	PNPSI = .3363	DPH12 = .1392E+07	
T = .00060	PHI = 213.48	PHIDOT = 296.32	G = -.0058	PSID = 314.11	PSIDOT = -293.82	PHITOT = 9.02
	F23 = 2.6929	F12 = 9.7673	PN = .3357	PNPSI = .3357	DPH12 = .1396E+07	
T = .00060	PHI = 213.50	PHIDOT = 298.07	G = -.0058	PSID = 314.09	PSIDOT = -295.10	PHITOT = 9.04
	F23 = 2.6951	F12 = 9.7661	PN = .3365	PNPSI = .3365	DPH12 = .1407E+07	
T = .00061	PHI = 213.52	PHIDOT = 299.83	G = -.0057	PSID = 314.07	PSIDOT = -296.38	PHITOT = 9.06
	F23 = 2.6946	F12 = 9.7655	PN = .3359	PNPSI = .3359	DPH12 = .1412E+07	
T = .00061	PHI = 213.54	PHIDOT = 301.60	G = -.0056	PSID = 314.05	PSIDOT = -297.66	PHITOT = 9.09
	F23 = 2.6968	F12 = 9.7644	PN = .3367	PNPSI = .3367	DPH12 = .1423E+07	
T = .00061	PHI = 213.56	PHIDOT = 303.37	G = -.0055	PSID = 314.03	PSIDOT = -298.95	PHITOT = 9.11
	F23 = 2.6964	F12 = 9.7637	PN = .3361	PNPSI = .3361	DPH12 = .1427E+07	
T = .00061	PHI = 213.58	PHIDOT = 305.16	G = -.0055	PSID = 314.00	PSIDOT = -300.24	PHITOT = 9.13
	F23 = 2.6986	F12 = 9.7625	PN = .3369	PNPSI = .3369	DPH12 = .1439E+07	
T = .00061	PHI = 213.61	PHIDOT = 306.96	G = -.0054	PSID = 313.98	PSIDOT = -301.53	PHITOT = 9.15

T = .05146	F23 = 2.9576	F12 = 10.7202	PN = .3459	PNPSI = .3459	DPH12 = .1762E+07
	PHI = 214.20	PHIDOT = 378.21	G = -.0034	PSID = 313.41	PSIDOT = -355.72
T = .05147	F23 = 2.9634	F12 = 10.7165	PN = .3478	PNPSI = .3478	DPH12 = .1795E+07
	PHI = 214.26	PHIDOT = 382.70	G = -.0032	PSID = 313.36	PSIDOT = -358.52
T = .05147	F23 = 2.9621	F12 = 10.7144	PN = .3459	PNPSI = .3459	DPH12 = .1807E+07
	PHI = 214.31	PHIDOT = 387.25	G = -.0030	PSID = 313.31	PSIDOT = -361.33
T = .05147	F23 = 2.9679	F12 = 10.7106	PN = .3478	PNPSI = .3478	DPH12 = .1841E+07
	PHI = 214.37	PHIDOT = 391.85	G = -.0028	PSID = 313.25	PSIDOT = -364.14
T = .05147	F23 = 2.9666	F12 = 10.7084	PN = .3458	PNPSI = .3458	DPH12 = .1853E+07
	PHI = 214.43	PHIDOT = 396.52	G = -.0026	PSID = 313.20	PSIDOT = -366.97
T = .05148	F23 = 2.9655	F12 = 9.7768	PN = .3469	PNPSI = .3468	DPH12 = .1883E+07
	PHI = 214.48	PHIDOT = 401.23	G = -.0024	PSID = 313.15	PSIDOT = -369.78
T = .05148	F23 = 2.9641	F12 = 9.7747	PN = .3447	PNPSI = .3447	DPH12 = .1896E+07
	PHI = 214.54	PHIDOT = 406.00	G = -.0023	PSID = 313.09	PSIDOT = -372.61
T = .05148	F23 = 2.9603	F12 = 9.7683	PN = .3453	PNPSI = .3453	DPH12 = .1924E+07
	PHI = 214.60	PHIDOT = 410.81	G = -.0021	PSID = 313.04	PSIDOT = -375.42
T = .05148	F23 = 2.9588	F12 = 9.7661	PN = .3432	PNPSI = .3432	DPH12 = .1938E+07
	PHI = 214.66	PHIDOT = 415.69	G = -.0019	PSID = 312.99	PSIDOT = -378.24
T = .05149	F23 = 2.9550	F12 = 9.7595	PN = .3437	PNPSI = .3437	DPH12 = .1967E+07
	PHI = 214.72	PHIDOT = 420.61	G = -.0017	PSID = 312.93	PSIDOT = -381.05
T = .05149	F23 = 2.9535	F12 = 9.7573	PN = .3415	PNPSI = .3415	DPH12 = .1981E+07
	PHI = 214.78	PHIDOT = 425.59	G = -.0015	PSID = 312.88	PSIDOT = -383.86
T = .05149	F23 = 2.9495	F12 = 9.7505	PN = .3419	PNPSI = .3419	DPH12 = .2011E+07
	PHI = 214.84	PHIDOT = 430.62	G = -.0013	PSID = 312.82	PSIDOT = -386.67
T = .05149	F23 = 2.9479	F12 = 9.7482	PN = .3396	PNPSI = .3396	DPH12 = .2025E+07
	PHI = 214.90	PHIDOT = 435.71	G = -.0010	PSID = 312.77	PSIDOT = -389.47
T = .05150	F23 = 2.9438	F12 = 9.7413	PN = .3401	PNPSI = .3401	DPH12 = .2056E+07
	PHI = 214.97	PHIDOT = 440.86	G = -.0008	PSID = 312.71	PSIDOT = -392.27
T = .05150	F23 = 2.9422	F12 = 9.7389	PN = .3377	PNPSI = .3377	DPH12 = .2071E+07
	PHI = 215.03	PHIDOT = 446.07	G = -.0006	PSID = 312.65	PSIDOT = -395.07
T = .05150	F23 = 2.6482	F12 = 9.7316	PN = .3382	PNPSI = .3382	DPH12 = .2104E+07
	PHI = 215.09	PHIDOT = 451.33	G = -.0004	PSID = 312.60	PSIDOT = -397.85
T = .05150	F23 = 2.6467	F12 = 9.7291	PN = .3357	PNPSI = .3357	DPH12 = .2119E+07
	PHI = 215.16	PHIDOT = 456.63	G = -.0002	PSID = 312.54	PSIDOT = -400.61
T = .05151	F23 = 2.4741	F12 = 10.5969	PN = .3045	PNPSI = .3045	DPH12 = .1957E+07
	PHI = 215.22	PHIDOT = 461.94	G = .0000	PSID = 312.48	PSIDOT = -403.33
	F23 = 2.4727	F12 = 10.5942	PN = .3021	PNPSI = .3021	DPH12 = .1972E+07

FREE MOTION

T = .05151	PHI = 133.41	PHIDOT = 461.94	PSI = 45.41	PSIDOT = -403.33	PHITOT = 1483.50
	FF12 = 10.356	FF23 = 2.342			
T = .05151	PHI = 133.47	PHIDOT = 470.16	PSI = 45.36	PSIDOT = -401.59	PHITOT = 1483.56
	FF12 = 10.384	FF23 = 2.62			
T = .05151	PHI = 133.54	PHIDOT = 478.37	PSI = 45.30	PSIDOT = -399.85	PHITOT = 1483.63
	FF12 = 10.383	FF23 = 2.625			
T = .05151	PHI = 133.61	PHIDOT = 486.65	PSI = 45.24	PSIDOT = -398.10	PHITOT = 1483.70
	FF12 = 10.378	FF23 = 2.631			
T = .05152	PHI = 133.68	PHIDOT = 494.97	PSI = 45.18	PSIDOT = -396.36	PHITOT = 1483.77
	FF12 = 10.378	FF23 = 2.631			
T = .05152	PHI = 133.75	PHIDOT = 503.37	PSI = 45.13	PSIDOT = -394.62	PHITOT = 1483.84
	FF12 = 10.373	FF23 = 2.637			
T = .05152	PHI = 133.82	PHIDOT = 511.80	PSI = 45.07	PSIDOT = -392.88	PHITOT = 1483.92
	FF12 = 10.372	FF23 = 2.637			
T = .05152	PHI = 133.90	PHIDOT = 520.3	PSI = 45.01	PSIDOT = -391.14	PHITOT = 1483.99
	FF12 = 10.367	FF23 = 2.644			
T = .05153	PHI = 133.97	PHIDOT = 528.87	PSI = 44.96	PSIDOT = -389.40	PHITOT = 1484.06
	FF12 = 10.367	FF23 = 2.644			
T = .05153	PHI = 134.05	PHIDOT = 537.51	PSI = 44.90	PSIDOT = -387.66	PHITOT = 1484.14
	FF12 = 10.361	FF23 = 2.651			

T = .05153	PHI = 134.13	PHIDOT = 546.19	PSI = 44.85	PSIDOT = -385.92	PHITOT = 1484.22
	FF12 = 10.360	FF23 = 2.651			
T = .05153	PHI = 134.21	PHIDOT = 554.92	PSI = 44.79	PSIDOT = -384.18	PHITOT = 1484.30
	FF12 = 10.365	FF23 = 2.395			
T = .05154	PHI = 134.29	PHIDOT = 563.63	PSI = 44.74	PSIDOT = -382.44	PHITOT = 1484.38
	FF12 = 10.365	FF23 = 2.395			
T = .05154	PHI = 134.37	PHIDOT = 572.30	PSI = 44.68	PSIDOT = -380.70	PHITOT = 1484.46
	FF12 = 10.373	FF23 = 2.400			
T = .05154	PHI = 134.45	PHIDOT = 580.93	PSI = 44.63	PSIDOT = -378.96	PHITOT = 1484.54
	FF12 = 10.373	FF23 = 2.400			
T = .05154	PHI = 134.53	PHIDOT = 589.44	PSI = 44.57	PSIDOT = -377.22	PHITOT = 1484.63
	FF12 = 10.406	FF23 = 2.665			
T = .05155	PHI = 134.62	PHIDOT = 597.57	PSI = 44.52	PSIDOT = -375.48	PHITOT = 1484.71
	FF12 = 10.406	FF23 = 2.665			
T = .05155	PHI = 134.71	PHIDOT = 605.78	PSI = 44.47	PSIDOT = -373.74	PHITOT = 1484.80
	FF12 = 10.399	FF23 = 2.673			
T = .05155	PHI = 134.79	PHIDOT = 614.04	PSI = 44.41	PSIDOT = -372.00	PHITOT = 1484.88
	FF12 = 10.399	FF23 = 2.673			
T = .05155	PHI = 134.88	PHIDOT = 622.40	PSI = 44.36	PSIDOT = -370.26	PHITOT = 1484.97
	FF12 = 10.392	FF23 = 2.681			
T = .05156	PHI = 134.97	PHIDOT = 630.81	PSI = 44.31	PSIDOT = -368.51	PHITOT = 1485.06
	FF12 = 10.392	FF23 = 2.681			

FF23MAX = 3.24

FF12MAX = 11.41

FF23MAX = 2.93

FF12MAX = 10.94

PHMAX = .66

NUMBER OF TURNS TO ARM= 25.779

APPENDIX B

**DYNAMICS OF ROTOR DRIVEN S&A MECHANISM WITH A TWO-PASS
INVOLUTE GEAR TRAIN AND A VERGE (PLATE PALLET) RUNAWAY ESCAPEMENT**

Description of Systems and Outline of Derivations

This appendix gives derivations for the complete mathematical model of an S&A mechanism, consisting of a spin driven rotor, a two pass, step-up involute gear train and a verge-type runaway escapement. Figures B-1 and B-2 show the two types of configurations to which this model may be adapted.

This work uses geometric and kinematic equations for the verge escapement developed in appendixes C through F. In addition, the dynamics of fuze gear trains is based on the work reported in reference B-1. As in previous efforts of Lowen and Tepper on the pin pallet escapement (refs B-1 and B-2), the following three motion regimes of the mechanism are considered:

Coupled Motion

The tip of the escape wheel is in constant contact with either the entrance or the exit working surface of the verge while it is driven by the rotor (gear no. 1) through the gear and pinion set no. 2. The entrance- as well as the exit-coupled motion differential equations, which differ from each other to some extent, are expressed in the escape wheel variable ϕ and are obtained by combining the solutions to the Newtonian force and moment expressions for the individual mechanism components.

Free Motion

The pallet and the escape wheel, gear train, rotor systems move independently of each other in this phase of the motion. Thus, there results one differential equation for the pallet in the variable ψ , and another one for the combined system in the escape wheel variable ϕ .

Impact

The formulation of the impact regime is similar to that shown in reference B-1 for the pin pallet escapement. Again, the moment of inertia of the escape wheel and pinion no. 3 also contains the referred mass properties of the rotor and gear and pinion set no. 2. This impact simulation is based on the classical angular impulse - momentum model, where a coefficient of restitution is used to account for the energy losses. Since it is assumed that the effect of the impact force between the escape wheel and the pallet is much greater than the effects due to the driving torque of the rotor and the various retarding torques due to friction, the latter are disregarded.

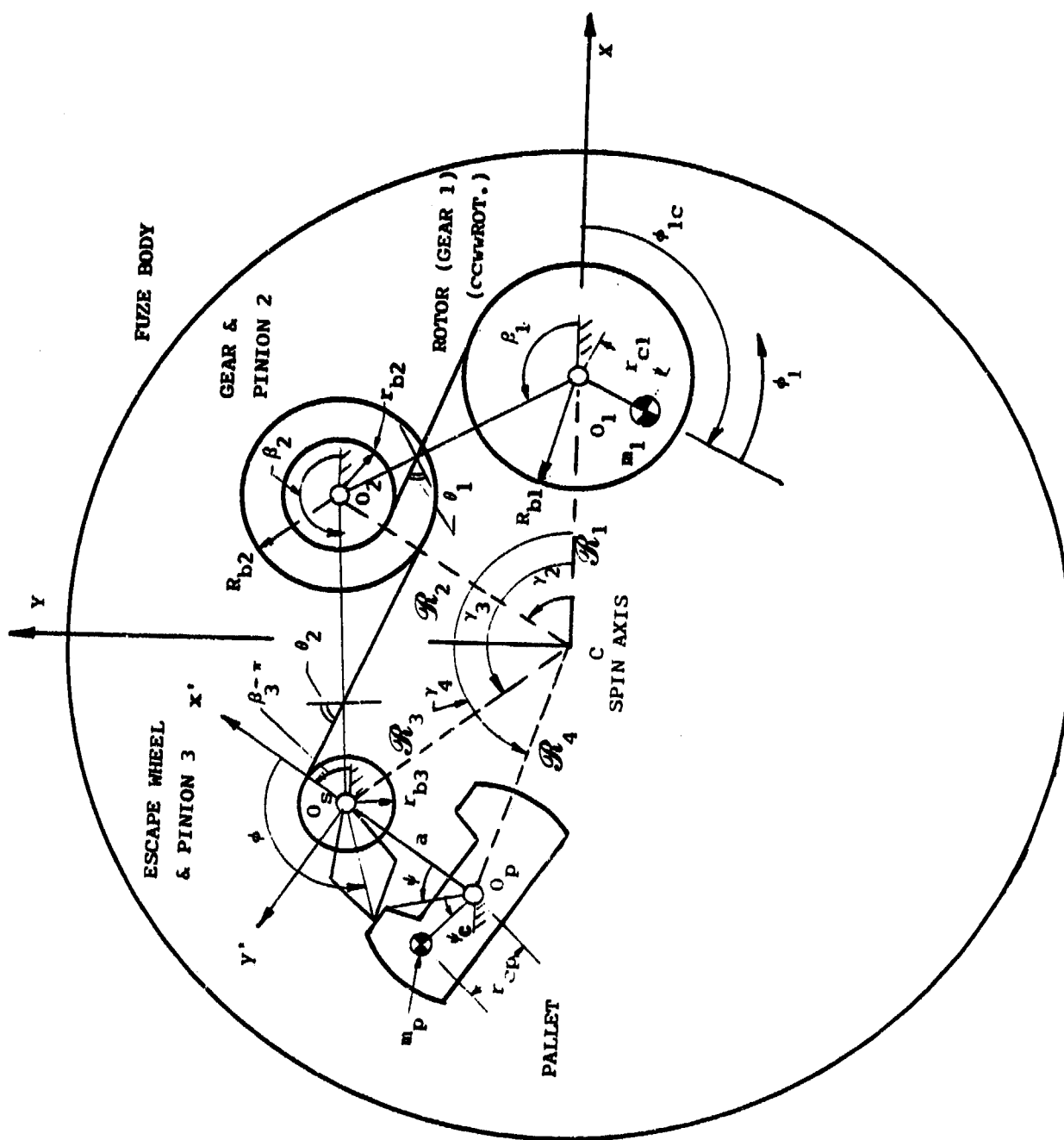


Figure B-1. Rotor driven S&A device, configuration no. 1

Treatment of Friction Forces

The influence of friction forces is considered both in the coupled and the free motion regimes. There is friction at the interface between the escape wheel and the pallet during coupled motion, and there is friction between the teeth of the gears at all of the pivots during both of these types of motions. As in reference B-1, the individual pivot friction torques are obtained by the algebraic addition of the two friction moments due to the x and y components of the normal bearing forces, rather than by the direct use of the resulting normal forces. This conservative approach to friction is necessary to avoid the difficulties which the presence of a square root term introduces into the solutions of the various differential equations.

Appendix E of reference B-1 proves that a change in sign of the coefficient of friction, both in the coupled and the free motion simulations of the gear train, including the rotor and the escape wheel (with the exception of the escape wheel-pallet interface), is sufficient to account for the changed directions of the friction forces encountered during a possible motion reversal of the gear train following an impact.

Geometry of Fuze Body Configurations

The following section contains derivations of expressions for the various fuze body angles associated with the pivot holes of both configurations of the two pass, step-up gear mechanisms. In addition, relationships between the unit vectors of the body-fixed X-Y and x'-y' systems (figs. B-1 and B-2) are given to describe certain escapement forces in terms of the primed coordinate system. (Note that the x'-axis is oriented along the escapement center-line O_p-O_s .) Finally a signum function is introduced so that common programming expressions for both configurations can be devised.

Fuze Body Configuration No. 1

The following relationships for the angles γ_1 , δ_1 , and β_1 for configuration no. 1 are indicated by figure B-3:

Angles γ_1

$$\gamma_2 = \cos^{-1} \left[\frac{\frac{1}{2} + \frac{1}{2} - (R_{p1} + r_{p2})^2}{2R_1R_2} \right] \quad (B1)$$

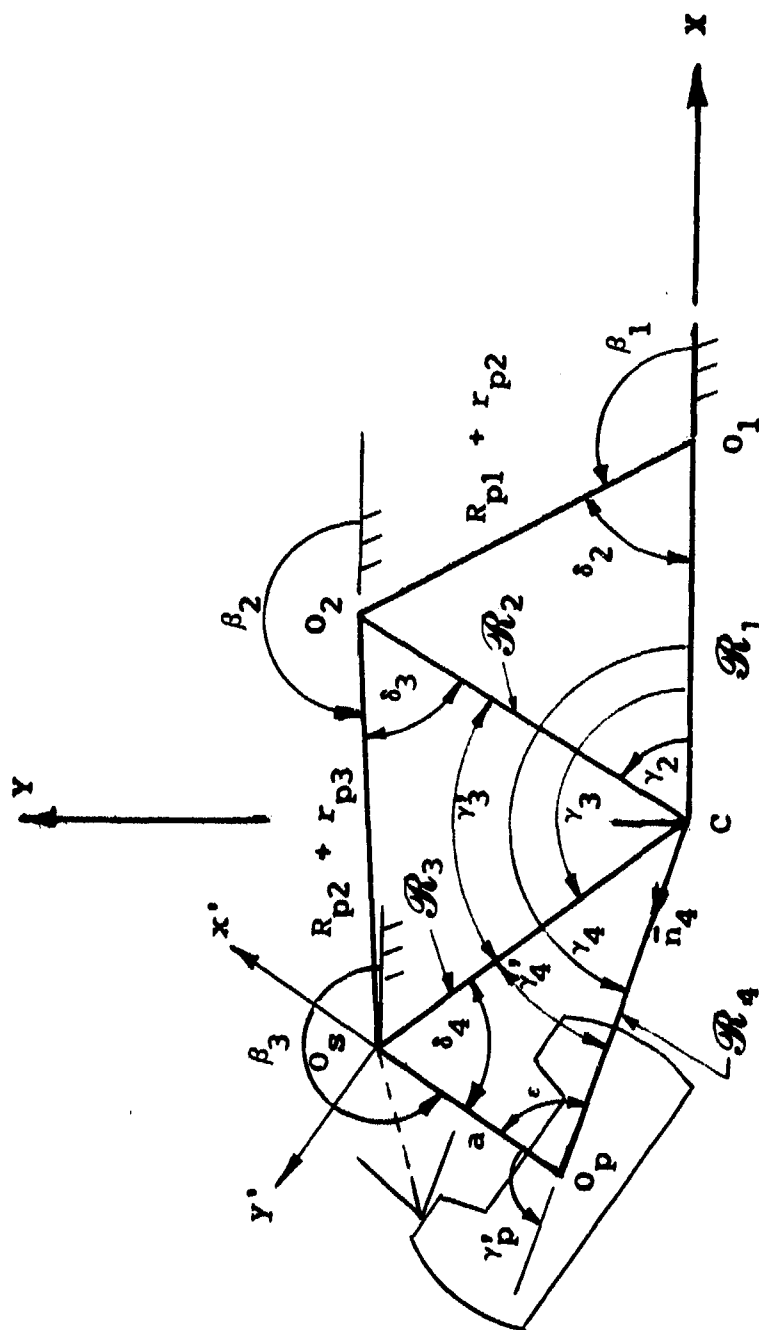


Figure B-3. Fuze body configuration no. 1

Further,

$$\gamma_3' = \cos^{-1} \left[\frac{R_2^2 + R_3^2 - (R_{p2} + r_{p3})^2}{2R_2 R_3} \right] \quad (B2)$$

Finally,

$$\gamma_3 = \gamma_2 + \gamma_3' \quad (B3)$$

The angle γ_4' is given by:

$$\gamma_4' = \cos^{-1} \left[\frac{R_3^2 + R_4^2 - a^2}{2R_3 R_4} \right] \quad (B4)$$

Then,

$$\gamma_4 = \gamma_3 + \gamma_4' \quad (B5)$$

Angles δ_1 . The angles δ_2 and δ_3 , as shown in figure B-3, become:

$$\delta_2 = \cos^{-1} \left[\frac{(R_{p1} + r_{p2})^2 + R_1^2 - R_2^2}{2R_1 (R_{p1} + r_{p2})} \right] \quad (B6)$$

and

$$\delta_3 = \cos^{-1} \left[\frac{(R_{p2} + r_{p3})^2 + R_2^2 - R_3^2}{2R_2 (R_{p2} + r_{p3})} \right] \quad (B7)$$

The angle δ_4 must take the pivot-to-pivot distance a of the escapement into account. Therefore,

$$\delta_4 = \cos^{-1} \left[\frac{a^2 + R_3^2 - R_4^2}{2aR_3} \right] \quad (B8)$$

Angles β_1 . The angles β_1 and β_2 become respectively:

$$\beta_1 = \pi - \delta_2 \quad (B9)$$

and

$$\beta_2 = \gamma_2 + \pi - \delta_3 \quad (B10)$$

The angle β_3 is found with the help of angle δ_4 of equation B8. Then,

$$\beta_3 = \gamma_3 + \pi - \delta_4 \quad (B11)$$

Figure B-3 shows the angle γ'_p between the positive x' -axis and the unit vector \bar{n}_4 . It is given by:

$$\gamma'_p = \pi - \epsilon \quad (B12)$$

where ϵ is obtained with the help of equations B4 and B8:

$$\epsilon = \pi - \delta_4 - \gamma'_4, \quad (B13)$$

and therefore:

$$\gamma'_p = \delta_4 + \gamma'_4 \quad (B14)$$

The unit vector \bar{n}_4 is expressed in terms of the primed coordinate system as follows:

$$\bar{n}_4 = \cos \gamma'_p \bar{i}' + \sin \gamma'_p \bar{j}' \quad (B15)$$

Further, the unit vectors \bar{i}' and \bar{j}' , when expressed in the X-Y system, become:

$$\bar{i}' = \cos (\beta_3 - \pi) \bar{i} + \sin (\beta_3 - \pi) \bar{j}$$

or

$$\bar{i}' = -\cos \beta_3 \bar{i} - \sin \beta_3 \bar{j} \quad (B16)$$

and

$$\bar{j}' = \bar{k}' \times \bar{i}' = \sin \beta_3 \bar{i} - \cos \beta_3 \bar{j} \quad (B17)$$

Fuze Body Configuration No. 2

The angles γ_1 , δ_1 , and β_1 of configuration no. 2 are defined in figure B-4.

Angles γ_1 . Since these angles are defined in the clockwise direction with respect to the body-fixed X-axis, their values must be negative.

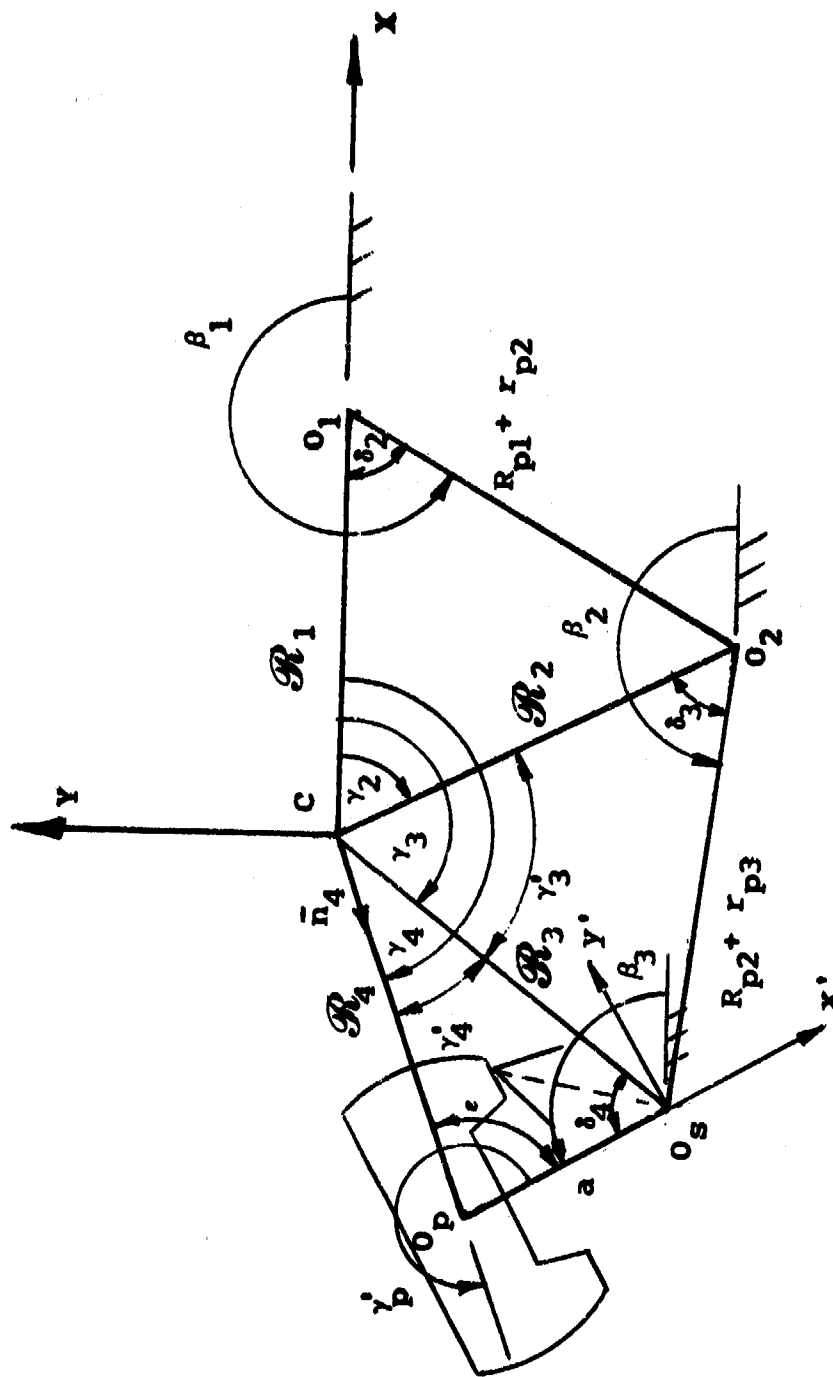


Figure B-4. Fuze body configuration no. 2

Then,

$$\gamma_2 = -\cos^{-1} \left[\frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2R_1 R_2} \right] \quad (B18)$$

Angle γ_3' is given by equation B2 and with that the following expression is obtained for γ_3 :

$$\gamma_3 = \gamma_2 - \gamma_3' \quad (B19)$$

The negative sign for γ_3' is necessary in order to make γ_3 negative.

The angle γ_4' is given by equation B4. It allows the following expression for angle γ_4 :

$$\gamma_4 = \gamma_3 - \gamma_4' \quad (B20)$$

Again, γ_4' must have a negative sign to make γ_4 negative.

Angles δ_1 . The angles δ_2 , δ_3 , and δ_4 can be taken directly from equations B6, B7, and B8, respectively.

Angles β_1 . Angle β_1 becomes:

$$\beta_1 = \pi + \delta_2 \quad (B21)$$

Further

$$\beta_2 = \gamma_2 + \pi + \delta_3 \quad (B22)$$

Finally,

$$\beta_3 = \gamma_3 + \pi + \delta_4 \quad (B23)$$

The angle γ_1' between the positive x' -axis and the unit vector \bar{n}_4 is shown in figure B-4. This angle is given by:

$$\gamma_1' = \pi + \varepsilon \quad (B24)$$

where

$$\varepsilon = \pi - \delta_4 - \gamma_4' \quad (B25)$$

Therefore

$$\gamma_1' = 2\pi - \delta_4 - \gamma_4' \quad (B26)$$

The unit vector \bar{n}_4 can again be expressed in terms of the primed coordinate system as

$$\bar{n}_4 = \cos \gamma'_p \bar{i}' + \sin \gamma'_p \bar{j}' \quad (B27)$$

The unit vectors \bar{i}' and \bar{j}' are expressed in the X-Y system as follows:

$$\bar{i}' = -\cos \beta_3 \bar{i} - \sin \beta_3 \bar{j} \quad (B28)$$

$$\bar{j}' = \sin \beta_3 \bar{i} - \cos \beta_3 \bar{j} \quad (B29)$$

Common Computational Expressions for Both Configurations

To find common programming expressions for all angles of both configurations (with the exception of the angles γ'_p of equations B14 and B26) the following signum function s_6 is introduced:

$$s_6 = +1 \text{ for configuration no. 1} \quad (B30)$$

$$s_6 = -1 \text{ for configuration no. 2} \quad (B31)$$

This leads to the following expressions:

According to equations B1 and B18:

$$\gamma_2 = s_6 \cos^{-1} \left[\frac{R_1^2 + R_2^2 - (R_{p1} + r_{p2})^2}{2R_1 R_2} \right] \quad (B32)$$

According to equation B2:

$$\gamma_3 = \cos^{-1} \left[\frac{R_2^2 + R_3^2 - (R_{p2} + r_{p3})^2}{2R_2 R_3} \right] \quad (B33)$$

According to equations B3 and B19:

$$\gamma_3 = \gamma_2 + s_6 \gamma'_3 \quad (B34)$$

According to equation B4:

$$\gamma_4 = \cos^{-1} \left[\frac{R_3^2 + R_4^2 - a^2}{2R_3 R_4} \right] \quad (B35)$$

According to equations B5 and B20:

$$\gamma_4 = \gamma_3 + s_6 \gamma_4' \quad (B36)$$

According to equations B6, B7, and B8, respectively

$$\delta_2 = \cos^{-1} \left[\frac{(R_{p1} + r_{p2})^2 + R_1^2 - R_2^2}{2R_1(R_{p1} + r_{p2})} \right] \quad (B37)$$

$$\delta_3 = \cos^{-1} \left[\frac{(R_{p2} + r_{p3})^2 + R_2^2 - R_3^2}{2R_2(R_{p2} + r_{p3})} \right] \quad (B38)$$

$$\delta_4 = \cos^{-1} \left[\frac{a^2 + R_3^2 - R_4^2}{2aR_3} \right] \quad (B39)$$

Dynamics of Pallet and Escape Wheel in Coupled Motion

This section shows derivations for both entrance- and exit-coupled motion differential equations. While the resulting combined differential equations are similar, they differ in a number of terms because of the inherent differences of the $\bar{n}_t - \bar{n}_n$ coordinate systems for the entrance and exit sides. While these derivations are given for configuration no. 1, they are also applicable to configuration no. 2 with the help of the signum function s_6 introduced in the previous section.

The analysis of the pallet is performed in the $x' - y'$ system for convenience, while that of the escape wheel uses the $X - Y$ system. An appropriate coordinate transformation makes it possible to combine the systems.

The coefficient of friction μ , is used at the escape wheel-pallet interface as well as at the pallet pivot, while the coefficient of friction μ serves to express the friction forces at the escape wheel pivot as well as at the escape wheel-pinion no. 2 tooth interface. (μ is also used in all other gear meshes and gear pivots.)

Signum Functions and Acceleration of Center of Mass of Pallet

To define the direction of the friction force of the escape wheel point S on the coincident pallet point T, the signum function s_4 is introduced. Thus,

$$s_4 = \frac{V_{S/T}}{|V_{S/T}|} \quad (B40)$$

where $V_{S/T}$ is given by equation C25 of appendix C. The signum function s_s serves for the determination of the direction of the friction forces acting on the pallet pivot. Then

$$s_s = \frac{\dot{\psi}}{|\dot{\psi}|} \quad (B41)$$

With the constant spin ω of the fuse body, the acceleration \bar{A}_{cp} of the center of mass of the pallet is given by (figs. B-1 and B-5):

$$\begin{aligned} \bar{A}_{cp} = & -\omega^2 R_4 \bar{n}_4 - (\omega + \dot{\psi})^2 r_{cp} [\cos(\psi + \psi_c) \bar{i}' + \sin(\psi + \psi_c) \bar{j}'] \\ & + \ddot{\psi} r_{cp} [-\sin(\psi + \psi_c) \bar{i}' + \cos(\psi + \psi_c) \bar{j}'] \end{aligned} \quad (B42)$$

Dynamics of Pallet and Escape Wheel for Entrance-Coupled Motion

A detailed free body diagram of the pallet for entrance-coupled motion is shown in figure B-5. The free body diagram of the escape wheel is simplified and presented for orientation only. A complete free body diagram of the escape wheel which includes all pivot and contact forces is given by figure B-6.

Force Equation of Pallet. Substitution of all forces into Newton's Law, together with the acceleration of the center of mass according to equation B42 furnishes:

$$\begin{aligned} P_n \bar{n}_n + \mu_1 s_4 P_n \bar{n}_t + F'_{xp} \bar{i}' - \mu_1 s_5 F'_{yp} \bar{i}' + F'_{yp} \bar{j}' + \mu_1 s_5 F'_{xp} \bar{j}' \\ = m_p \{ -\omega^2 R_4 \bar{n}_4 - (\omega + \dot{\psi})^2 r_{cp} [\cos(\psi + \psi_c) \bar{i}' + \sin(\psi + \psi_c) \bar{j}'] \\ + \ddot{\psi} r_{cp} [-\sin(\psi + \psi_c) \bar{i}' + \cos(\psi + \psi_c) \bar{j}'] \} \end{aligned} \quad (B43)$$

(For nomenclature, consult figures B-1 and B-5, as well as reference B-1.)

Moment Equation of Pallet. The moment equation of the pallet must be written with the understanding that pivot point O_p is an accelerated point. Thus,

$$\bar{M}_{op} = -\ddot{\bar{r}}_{op} \times m_p \bar{r}_{cp} + \bar{H}_{op} \quad (B44)$$

where

\bar{M}_{op} = sum of all external moments with respect to pivot O_p

$\ddot{\mathbf{r}}_{op}$ = absolute acceleration of point O_p

$\dot{\mathbf{h}}_{op}$ = time rate of change of angular momentum of the pallet with respect to point O_p .

Since the spin angular velocity $\bar{\omega}$ of the fuze body is constant, equation B44 takes the following form:

$$\bar{\mathbf{M}}_{op} = -(\bar{\omega}^2 \bar{r}_4 \bar{\mathbf{n}}_4) \times \bar{\mathbf{m}}_p \bar{\mathbf{r}}_{cp} [\cos(\psi + \psi_c) \bar{\mathbf{i}}' + \sin(\psi + \psi_c) \bar{\mathbf{j}}'] + I_p \ddot{\psi} \bar{\mathbf{k}} \quad (\text{B45})$$

If $\bar{\mathbf{n}}_4$ is substituted according to equation B27, the above becomes in scalar terms:

$$M_{op} = I_p \ddot{\psi} - \bar{\mathbf{m}}_p \bar{\mathbf{r}}_{cp} \bar{r}_4 \omega^2 \sin(\gamma_p' - \psi - \psi_c) \quad (\text{B46})$$

To find the value of $\bar{\mathbf{M}}_{op}$ consider figure B-5.

$$\bar{\mathbf{M}}_{op} = D_1' \bar{\mathbf{n}}_t \times \bar{\mathbf{P}}_n \bar{\mathbf{n}}_n + C_1' \bar{\mathbf{n}}_n \times \mu_1 s_4 \bar{\mathbf{P}}_n \bar{\mathbf{n}}_t - \rho_p \mu_1 s_5 (\tilde{\mathbf{F}}_{xp} + \tilde{\mathbf{F}}_{yp}) \bar{\mathbf{k}} \quad (\text{B47})$$

or, in scalar terms

$$M_{op} = D_1' P_n - C_1' \mu_1 s_4 P_n - \rho_p \mu_1 s_5 (\tilde{F}_{xp} + \tilde{F}_{yp}) \quad (\text{B48})$$

When equation B48 is substituted into equation B46, the final moment expression for the pallet is obtained:

$$\begin{aligned} P_n [D_1' - C_1' \mu_1 s_4] - \rho_p \mu_1 s_5 (\tilde{F}_{xp} + \tilde{F}_{yp}) \\ = I_p \ddot{\psi} - \bar{\mathbf{m}}_p \bar{r}_4 \bar{\mathbf{r}}_{cp} \omega^2 \sin(\gamma_p' - \psi - \psi_c) \end{aligned} \quad (\text{B49})$$

As originally discussed in an ARRADCOM report (ref B-3), \tilde{F}_{xp} and \tilde{F}_{yp} represent conservatively evaluated pivot force components which assure that the pivot friction moments are opposed to the rotation at all times.

The pivot friction components F'_{xp} and F'_{yp} are first obtained from the following component expressions of equation B43. Subsequently, they are transformed to become \tilde{F}_{xp} and \tilde{F}_{yp} , respectively.

$$\begin{aligned} -P_n \sin(\psi + \alpha) + \mu_1 s_4 P_n \cos(\psi + \alpha) + F'_{xp} - \mu_1 s_5 F'_{yp} \\ = \bar{\mathbf{m}}_p [-\omega^2 \bar{r}_4 \cos \gamma_p' - (\omega + \dot{\psi})^2 \bar{\mathbf{r}}_{cp} \cos(\psi + \psi_c) - \ddot{\psi} \bar{\mathbf{r}}_{cp} \sin(\psi + \psi_c)] \end{aligned} \quad (\text{B50})$$

and

$$P_n \cos(\psi + \alpha) + \mu_1 s_4 P_n \sin(\psi + \alpha) + \mu_1 s_5 F'_{xp} + F'_{yp} \quad (B51)$$

$$= m_p [-\omega^2 R_4 \sin \gamma'_p - (\omega + \dot{\psi})^2 r_{cp} \sin(\psi + \psi_c) + \ddot{\psi} r_{cp} \cos(\psi + \psi_c)]$$

Simultaneous solution of the above furnishes:

$$\tilde{F}_{yp} = P_n A_1 + \omega^2 A_2 \pm 2 \frac{\omega^2}{|\omega|} \dot{\psi} A_3 \pm \dot{\psi}^2 A_3 \pm \ddot{\psi} A_4 \quad (B52)$$

$$\tilde{F}_{xp} = P_n A_5 + \omega^2 A_6 \pm 2 \frac{\omega^2}{|\omega|} \dot{\psi} A_7 \pm \dot{\psi}^2 A_7 \pm \ddot{\psi} A_8 \quad (B53)$$

where

$$A_1 = \left| \frac{-\mu_1 (s_4 + s_5) \sin(\psi + \alpha) - (1 - s_4 s_5 \mu_1^2) \cos(\psi + \alpha)}{1 + \mu_1^2} \right| \quad (B54)$$

$$A_2 = \left| \frac{m_p [R_4 (\sin \gamma'_p - \mu_1 s_5 \cos \gamma'_p) + r_{cp} (\sin(\psi + \psi_c) - \mu_1 s_5 \cos(\psi + \psi_c))] }{1 + \mu_1^2} \right| \quad (B55)$$

$$A_3 = \left| \frac{m_p r_{cp} [\sin(\psi + \psi_c) - \mu_1 s_5 \cos(\psi + \psi_c)] }{1 + \mu_1^2} \right| \quad (B56)$$

$$A_4 = \left| \frac{m_p r_{cp} [\cos(\psi + \psi_c) + \mu_1 s_5 \sin(\psi + \psi_c)] }{1 + \mu_1^2} \right| \quad (B57)$$

$$A_5 = \left| \frac{\mu_1 (s_4 + s_5) \cos(\psi + \alpha) + (1 - s_4 s_5 \mu_1^2) \sin(\psi + \alpha)}{1 + \mu_1^2} \right| \quad (B58)$$

$$A_6 = \left| \frac{m_p [-R_4 (\cos \gamma'_p + \mu_1 s_5 \sin \gamma'_p) - r_{cp} (\cos(\psi + \psi_c) + \mu_1 s_5 \sin(\psi + \psi_c))] }{1 + \mu_1^2} \right| \quad (B59)$$

$$A_7 = \left| \frac{m_p r_{cp} [\cos(\psi + \psi_c) + \mu_1 s_5 \sin(\psi + \psi_c)]}{1 + \mu_1^2} \right| \quad (B60)$$

$$A_8 = \left| \frac{m_p r_{cp} [\sin(\psi + \psi_c) - \mu_1 s_5 \cos(\psi + \psi_c)]}{1 + \mu_1^2} \right| \quad (B61)$$

The factor $\omega^2/|\omega|$ is introduced in place of ω to assure that the quantity is positive regardless of direction of spin. (This too, assures that the friction moments oppose rotation. The driving moment is proportional to ω^2 and, therefore, independent of spin direction.) To make the final decision concerning the signs in equations B52 and B53, these forces are now substituted into moment equation B49, and the influence of the direction of rotation on each of the resulting moment computations is explored:

$$\begin{aligned} & P_n [D_1' - C_1' \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_5)] \pm \rho_p \mu_1 s_5 \omega^2 (A_2 + A_6) \\ & \pm 2\rho_p \mu_1 s_5 \frac{\omega^2}{|\omega|} \dot{\psi} (A_3 + A_7) \pm \rho_p \mu_1 s_5 \dot{\psi}^2 (A_3 + A_7) \pm \rho_p \mu_1 s_5 \ddot{\psi} (A_4 + A_8) \quad (B62) \\ & = I_p \ddot{\psi} - m_p r_{cp} \rho_p \omega^2 \sin(\gamma_p' - \psi - \psi_c) \end{aligned}$$

With s_5 positive for positive rotation, and vice versa, and with all other parameters positive at all times, the following moment components of equation B62 must have negative signs during positive rotation:

$$-P_n \rho_p \mu_1 s_5 (A_1 + A_5) \quad (B63)$$

$$-\rho_p \mu_1 s_5 \omega^2 (A_2 + A_6) \quad (B64)$$

$$-\rho_p \mu_1 s_5 \dot{\psi}^2 (A_3 + A_7) \quad (A65)$$

The sign of the term containing $\dot{\psi}$ is negative and is controlled by the sign of ψ . Therefore, the signum operator s_5 is omitted and the term becomes:

$$-2\rho_p \mu_1 \frac{\omega^2}{|\omega|} \dot{\psi} (A_3 + A_7) \quad (B66)$$

The choice of sign for the friction moment term in equation B62, which is proportional to the pallet angular acceleration $\ddot{\psi}$, is discussed in detail in appendix F of reference B-1. This work leads to the computational rules of equations B73 and B74 below which deal with the sign in the expressions for the effective moment of inertia I_{pr} . (The signum function s_5 has now been omitted.)

With these considerations, equation B62^{B-1} now becomes

$$P_n A_{18} - \omega^2 A_{19} - 2 \frac{\omega^2}{|\omega|} \dot{\psi} A_{20} - \dot{\psi}^2 A_{21} \quad (B68)$$

$$= I_{PR} \ddot{\psi} - m_p r_{cp} R_4 \omega^2 \sin(\gamma'_p - \psi - \psi_c)$$

where^{B-2}

$$A_{18} = D'_1 - C'_1 \mu_1 s_4 - \rho_p \mu_1 s_5 (A_1 + A_5) \quad (B69)$$

$$A_{19} = \rho_p \mu_1 s_5 (A_2 + A_6) \quad (B70)$$

$$A_{20} = \rho_p \mu_1 (A_3 + A_7) \quad (B71)$$

$$A_{21} = \rho_p \mu_1 s_5 (A_3 + A_7) \quad (B72)$$

$$I_{PR} = I_p + A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have identical signs} \quad (B73)$$

$$I_{PR} = I_p - A_{22}, \text{ when } \dot{\psi} \text{ and } \ddot{\psi} \text{ have opposite signs}^{\text{B-3}} \quad (B74)$$

$$A_{22} = \rho_p \mu_1 (A_4 + A_8) \quad (B75)$$

Equation B68 is now used to find an expression for the contact force P_n . This expression will later make it possible to establish a single differential equation for the escapement in coupled motion. Thus,

$$P_n = \frac{I_{PR} \ddot{\psi} + A_{21} \dot{\psi}^2 + 2 \frac{\omega^2}{|\omega|} A_{20} \dot{\psi} + \omega^2 A_{19} - m_p r_{cp} R_4 \omega^2 \sin(\gamma'_p - \psi - \psi_c)}{A_{18}} \quad (B76)$$

B-1 Note that there is no equation B67.

B-2 The parameters A_n are not sequential at this point. A_9 to A_{17} may be found in equations B90ⁿ to B95 and B97 to B99 in conjunction with the work on the escape wheel.

B-3 Care must be taken that $I_p - A_{22}$ does not become negative. If this occurs, I_{PR} must be set equal to zero.

It is now necessary to write equation B76 in terms of the angular velocity $\dot{\phi}$ and the angular acceleration $\ddot{\phi}$ of the escape wheel so that it may later be equated to a similar expression for the escape wheel.

Thus, with the help of equations C19 and C26 of appendix C, the contact force becomes:

$$P_n = \frac{1}{A_{18}} [I_{PR} U \ddot{\phi} + (A_{21} U^2 + I_{PR} V) \dot{\phi}^2 + 2 \frac{\omega^2}{|\omega|} A_{20} U \dot{\phi} + \omega^2 A_{19} - m_p r_{cp} R_4 \omega^2 \sin(\gamma'_p - \psi - \psi_c)] \quad (B77)$$

Escape Wheel Analysis. A detailed free body diagram of the escape wheel and pinion no. 3 in entrance-coupled motion is shown in figure B-6. The pivot forces F_{x3} and F_{y3} as well as the contact force F_{23} and the force T_3 are now defined in the general X-Y system. This makes it necessary to transform the unit vectors \bar{n}_t and \bar{n}_n from the $x' - y'$ system to the X-Y system. Since

$$\bar{i}' = \cos(\beta_3 - \pi) \bar{i} + \sin(\beta_3 - \pi) \bar{j} \quad (B78)$$

or

$$\bar{i}' = -\cos\beta_3 \bar{i} - \sin\beta_3 \bar{j}, \quad (B79)$$

and

$$\bar{j}' = \sin\beta_3 \bar{i} - \cos\beta_3 \bar{j} \quad (B80)$$

the unit vectors \bar{n}_t and \bar{n}_n can now be determined with the help of equations C5 and C6 of appendix C. Thus,

$$\bar{n}_t = -\cos(\psi + \alpha + \beta_3) \bar{i} - \sin(\psi + \alpha + \beta_3) \bar{j} \quad (B81)$$

$$\bar{n}_n = \sin(\psi + \alpha + \beta_3) \bar{i} - \cos(\psi + \alpha + \beta_3) \bar{j} \quad (B82)$$

Parallel work is given in appendix B of reference B-1.

Force Equation of Escape Wheel. Force equilibrium is obtained with the help of the following expression, based on figure B-6:

$$\begin{aligned} -P_n \bar{n}_n - \mu_1 s_4 P_n \bar{n}_t + F_{23} \bar{n}_{23} + \mu s_2 F_{23} \bar{n}_{N23} + \bar{T}_3 \\ + F_{x3} \bar{i} + \mu F_{y3} \bar{i} + \mu F_{x3} \bar{j} - F_{y3} \bar{j} = 0 \end{aligned} \quad (B83a)$$

CCW Rotation

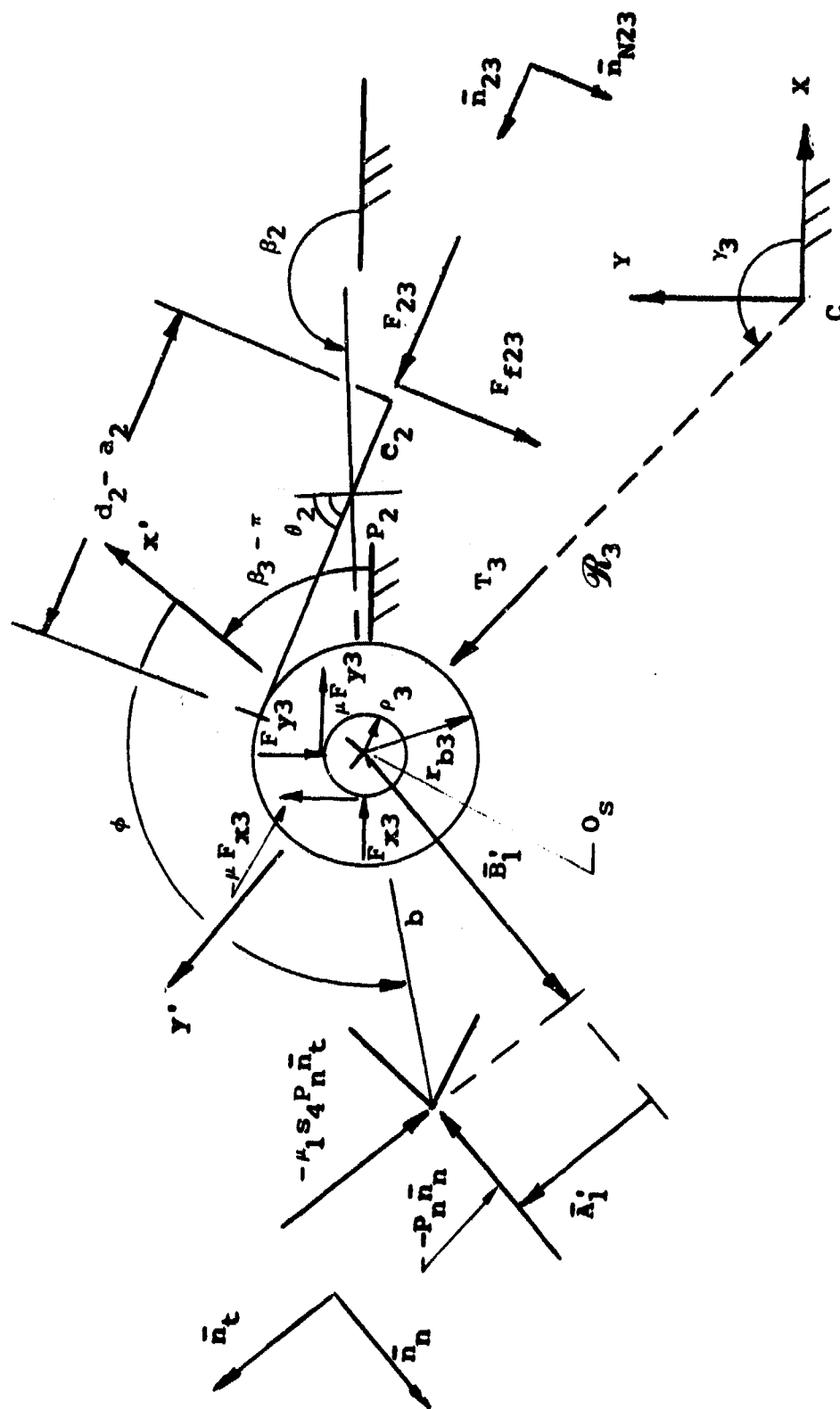


Figure B-6. Free body diagram of escape wheel and pinion 3 in entrance-coupled motion

The signum function s_2 is defined in reference B-3. Further, according to reference B-1, the D'Alembert force \bar{T}_3 is given by

$$\bar{T}_3 = m_3 R_3 \omega^2 (\cos \gamma_3 \bar{i} + \sin \gamma_3 \bar{j}) \quad (B83b)$$

Moment Equation of Escape Wheel. Again, based on the nomenclature of figure B-6, the moment equation of the escape wheel is given by:

$$\begin{aligned} A_1 \bar{n}_t \times (-P_n) \bar{n}_n + B_1 \bar{n}_n \times (-\mu_1 s_4 P_n) \bar{n}_t \\ - \mu \rho_3 (\tilde{F}_{x3} + \tilde{F}_{y3}) \bar{k} + r_{b3} F_{23} \bar{k} - \mu s_2 (d_2 - a_2) F_{23} \bar{k} = I_3 \ddot{\phi} \bar{k} \end{aligned} \quad (B84)$$

This becomes in scalar form:

$$\begin{aligned} -P_n (A_1' - B_1' \mu_1 s_4) - \mu \rho_3 (\tilde{F}_{x3} + \tilde{F}_{y3}) + r_{b3} F_{23} \\ - \mu s_2 (d_2 - a_2) F_{23} = I_3 \ddot{\phi} \end{aligned} \quad (B85)$$

The pivot force components F_{x3} and F_{y3} , which eventually become \tilde{F}_{x3} and \tilde{F}_{y3} , are now determined with the help of the following scalar component expressions of equation B83:

$$\begin{aligned} -P_n \sin(\psi + \alpha + \beta_3) + \mu_1 s_4 P_n \cos(\psi + \alpha + \beta_3) + T_3 \cos \gamma_3 \\ + F_{23} \sin(\beta_2 + \theta_2) + \mu s_2 F_{23} \cos(\beta_2 + \theta_2) + F_{x3} + \mu F_{y3} = 0 \end{aligned} \quad (B86)$$

and

$$\begin{aligned} P_n \cos(\psi + \alpha + \beta_3) + \mu_1 s_4 P_n \sin(\psi + \alpha + \beta_3) + T_3 \sin \gamma_3 \\ - F_{23} \cos(\beta_2 + \theta_2) + \mu s_2 F_{23} \sin(\beta_2 + \theta_2) + \mu F_{x3} - F_{y3} = 0 \end{aligned} \quad (B87)$$

Simultaneous solution of the above yields the following "conservative" pivot force components:

$$\tilde{F}_{y3} = P_n A_9 + F_{23} A_{10} + T_3 A_{11} \quad (B88)$$

$$\tilde{F}_{x3} = P_n A_{12} + F_{23} A_{13} + T_3 A_{14} \quad (B89)$$

Since there are no kinematic terms, it is most conservative to sum all terms and use the absolute values of A_9 - A_{14} as follows:

$$A_9 = \left| \frac{(\mu_1 s_4 + \mu) \sin(\psi + \alpha + \beta_3) + (1 - \mu \mu_1 s_4) \cos(\psi + \alpha + \beta_3)}{1 + \mu^2} \right| \quad (B90)$$

$$A_{10} = \left| \frac{-\mu(1-s_2) \sin(\beta_2 + \theta_2) - (1 + \mu^2 s_2) \cos(\beta_2 + \theta_2)}{1 + \mu^2} \right| \quad (B91)$$

$$A_{11} = \left| \frac{\sin \gamma_3 - \mu \cos \gamma_3}{1 + \mu^2} \right| \quad (B92)$$

$$A_{12} = \left| \frac{(1 - \mu \mu s_4) \sin(\psi + \alpha + \beta_3) - (s_4 \mu_1 + \mu) \cos(\psi + \alpha + \beta_3)}{1 + \mu^2} \right| \quad (B93)$$

$$A_{13} = \left| \frac{-(1 + \mu^2 s_2) \sin(\beta_2 + \theta_2) + \mu(1 - s_2) \cos(\beta_2 + \theta_2)}{1 + \mu^2} \right| \quad (B94)$$

$$A_{14} = \left| \frac{\cos \gamma_3 + \mu \sin \gamma_3}{1 + \mu^2} \right| \quad (B95)$$

Substitution of equations B88 and B89 into the moment equation B85 and subsequent rearrangement lead to the following expression for the contact force P_n in terms of escape wheel quantities:

$$P_n = \frac{-I_3 \ddot{\phi} + F_{23} A_{15} - T_3 A_{16}}{A_{17}} \quad (B96)$$

where

$$A_{15} = r_{b3} - \mu[s_2(d_2 - a_2) + \rho_3(A_{10} + A_{13})] \quad (B97)$$

$$A_{16} = \mu \rho_3 (A_{11} + A_{14}) \quad (B98)$$

$$A_{17} = A_1' - \mu_1 s_4 B_1' + \mu \rho_3 (A_9 + A_{12}) \quad (B99)$$

Combined Entranced-Coupled Motion Differential Equation. Equations B77 and B96 are now set equal to each other. This furnishes the following combined motion differential equation for the escapement:

$$[I_3 A_{18} + I_{PR} A_{17} U] \ddot{\phi} + [I_{PR} A_{17} V + A_{17} A_{21} U^2] \dot{\phi}^2 + 2 \frac{\omega^2}{|\omega|} A_{17} A_{20} U \dot{\phi} \quad (B100)$$

$$= A_{15} A_{18} F_{23} - A_{16} A_{18} T_3 - A_{17} \omega^2 [A_{19} - m_p r_{cp} R_4 \sin(\gamma'_p - \psi - \psi_c)]$$

Dynamics of Pallet and Escape Wheel for Exit-Coupled Motion

A free body diagram of the pallet for exit-coupled motion, together with a simplified representation of the escape wheel is shown in figure B-7. When this figure is compared with figure B-5, which depicts entrance-coupled motion, it is noted that now

$$\ddot{P}_n = -P_n \ddot{n}_n \quad (B101)$$

This sign change is reflected both in the force and in the moment equation.

Force Equations of Pallet. When the scalar force equations B50 and B51 are altered to account for the above change, they have the following form:

$$P_n \sin(\psi + \alpha) + \mu_1 s_4 P_n \cos(\psi + \alpha) + F'_{xp} - \mu_1 s_5 F'_{yp} \quad (B102)$$

$$= m_p [-\omega^2 R_4 \cos \gamma'_p - (\omega + \dot{\psi})^2 r_{cp} \cos(\psi + \psi_c) - \ddot{\psi} r_{cp} \sin(\psi + \psi_c)]$$

$$-P_n \cos(\psi + \alpha) + \mu_1 s_4 P_n \sin(\psi + \alpha) + \mu_1 s_5 F'_{xp} + F'_{yp} \quad (B103)$$

$$= m_p [-\omega^2 R_4 \sin \gamma'_p - (\omega + \dot{\psi})^2 r_{cp} \sin(\psi + \psi_c) + \ddot{\psi} r_{cp} \cos(\psi + \psi_c)]$$

Simultaneous solution of the above shows that only the factors A_1 and A_5 as given by equations B54 and B58 need be changed. These will now be called AA_1 and AA_5 . Then,

$$AA_1 = \left| \frac{\mu_1 (s_5 - s_4) \sin(\psi + \alpha) + (1 + \mu_1^2 s_4 s_5) \cos(\psi + \alpha)}{1 + \mu_1^2} \right| \quad (B104)$$

and

$$AA_5 = \left| \frac{\mu_1 (s_5 - s_4) \cos(\psi + \alpha) - (1 + \mu_1^2 s_4 s_5) \sin(\psi + \alpha)}{1 + \mu_1^2} \right| \quad (B105)$$

Moment Equation of Pallet. The sign change of the contact force P_n reflects itself in the scalar moment equation B49 as follows:

$$\begin{aligned} P_n [-D'_1 - C'_1 \mu_1 s_4] - \rho_p \mu_1 s_5 (\bar{F}_{xp} + \bar{F}_{yp}) \\ = I_p \ddot{\psi} - m_p R_4 r_{cp} \omega^2 \sin(\gamma'_p - \psi - \psi_c) \end{aligned} \quad (B106)$$

(Note change of sign of D'_1 .)

Following the same path as for the entrance contact, it can be shown that, with the exception of the factor A_{18} , equation B76 for the contact force P_n remains unchanged. Then,

$$P_n = \frac{I_{PR} \ddot{\psi} + A_{21} \dot{\psi}^2 + 2 \frac{\omega^2}{|\omega|} A_{20} \dot{\psi} + \omega^2 A_{19} - m_p r_{cp} R_4 \omega^2 \sin(\gamma'_p - \psi - \psi_c)}{AA_{18}} \quad (B107)$$

where

$$AA_{18} = -[D'_1 + C'_1 \mu_1 s_4 + \rho_p \mu_1 s_5 (AA_1 + AA_5)] \quad (B108)$$

Finally, the expression equivalent to equation B77 becomes:

$$\begin{aligned} P_n = \frac{1}{AA_{18}} [I_{PR} U \ddot{\phi} + (A_{21} U^2 + I_{PR} V) \dot{\phi}^2 + 2 \frac{\omega^2}{|\omega|} A_{20} U \dot{\phi} \\ + \omega^2 A_{19} - m_p r_{cp} R_4 \omega^2 \sin(\gamma'_p - \psi - \psi_c)] \end{aligned} \quad (B109)$$

Force Equations of Escape Wheel. A free body diagram of the escape wheel in exit-coupled motion is shown in figure B-8. When the scalar force equations B86 and B87 for the escape wheel in entrance-coupled motion are adjusted to account for this condition, the following expressions are obtained:

$$\begin{aligned} P_n \sin(\psi + \alpha + \beta_3) + \mu_1 s_4 P_n \cos(\psi + \alpha + \beta_3) + T_3 \cos \gamma_3 \\ + F_{23} \sin(\beta_2 + \theta_2) + \mu s_2 F_{23} \cos(\beta_2 + \theta_2) + F_{x3} + \mu F_{y3} = 0 \end{aligned} \quad (B110)$$

and

$$\begin{aligned} -P_n \cos(\psi + \alpha + \beta_3) + \mu_1 s_4 P_n \sin(\psi + \alpha + \beta_3) + T_3 \sin \gamma_3 \\ - F_{23} \cos(\beta_2 + \theta_2) + \mu s_2 F_{23} \sin(\beta_2 + \theta_2) + \mu F_{x3} - F_{y3} = 0 \end{aligned} \quad (B111)$$

[illegible]

Figure B-8. Free body diagram of escape wheel and pinion 3 in exit-coupled motion

Simultaneous solution of the above for F_{x3} and F_{y3} shows that certain coefficients of these pivot forces will differ from those given in the solutions for entrance-coupled motion. Thus,

$$\tilde{F}_{y3} = P_n AA_9 + F_{23} A_{10} + T_3 A_{11} \quad (B112)$$

$$\tilde{F}_{x3} = P_n AA_{12} + F_{23} A_{13} + T_3 A_{14} \quad (B113)$$

where A_{10} , A_{11} , A_{13} , and A_{14} are given by equations B91, B92, B94, and B95, respectively. The new coefficients AA_9 and AA_{12} are defined as follows:

$$AA_9 = \left| \frac{(\mu_1 s_4 - \mu) \sin(\psi + \alpha + \beta_3) - (1 + s_4 \mu \mu_1) \cos(\psi + \alpha + \beta_3)}{1 + \mu^2} \right| \quad (B114)$$

$$AA_{12} = \left| \frac{-(1 + \mu \mu_1 s_4) \sin(\psi + \alpha + \beta_3) + (\mu - \mu_1 s_4) \cos(\psi + \alpha + \beta_3)}{1 + \mu^2} \right| \quad (B115)$$

Moment Equation of Escape Wheel. Modification of the escape wheel moment equation B84 for exit contact gives:

$$\begin{aligned} A'_1 \bar{n}_t \times P_n \bar{n}_n + \bar{B}'_1 \times (-\mu_1 s_4 P_n) \bar{n}_t - \mu \rho_3 (\tilde{F}_{x3} + \tilde{F}_{y3}) \bar{k} \\ + r_{b3} F_{23} \bar{k} - \mu s_2 (d_2 - a_2) F_{23} \bar{k} = I_3 \ddot{\phi} \bar{k} \end{aligned} \quad (B116)$$

Substitution of equations B112 and B113 into the scalar form of equation B116 above furnishes the following expression for P_n :

$$P_n = \frac{-I_3 \ddot{\phi} + F_{23} A_{15} - T_3 A_{16}}{AA_{17}} \quad (B117)$$

where A_{15} and A_{16} are given by equations B97 and B98, respectively. The factor AA_{17} is new; i.e.,

$$AA_{17} = -A'_1 - \mu_1 s_4 B'_1 + \mu \rho_3 (AA_9 + AA_{12}) \quad (B118)$$

Combined Exit-Coupled Motion Differential Equation. Equations B109 and B117 are now equated to each other. This furnishes the combined exit-coupled motion differential equation:

$$\begin{aligned}
& [I_3 AA_{18} + I_{PR} AA_{17} U] \ddot{\phi} + [I_{PR} AA_{17} V + AA_{17} A_{21} U^2] \dot{\phi}^2 \\
& + 2 \frac{\omega^2}{|\omega|} AA_{17} A_{20} U \dot{\phi} \\
& = A_{15} AA_{18} F_{23} - A_{16} AA_{18} T_3 - AA_{17} \omega^2 [A_{19} - m_p r_{cp}^2 \sin(\gamma_p' - \psi - \psi_c)]
\end{aligned}
\tag{B119}$$

Dynamics of Rotor (Gear No. 1)

(Applicable to both configurations with appropriate choice of s_6 . See also reference B-1.)

A free body diagram of the rotor of configuration no. 1, which moves in a counterclockwise direction, is shown in figure B-9. The acceleration of its center of mass is given by equation A122 of appendix A of reference B-1.

Since the motion of the rotor must be expressed in terms of the escape wheel variable ϕ , use must be made of the following relationships:

$$\dot{\phi}_1 = N_{31} \dot{\phi} \tag{B120}$$

and

$$\ddot{\phi}_1 = N_{31} \ddot{\phi} \tag{B121}$$

where

$$N_{31} = \frac{N_{P3} \times N_{P2}}{N_{G2} \times N_{G1}} \tag{B122}$$

The rotor angle $\phi_{1C} + \phi_1$ is expressed in terms of the total escape wheel rotation ϕ_T :

$$\phi_{1C} + \phi_1 = \phi_{1C} + N_{31} \phi_T \tag{B123}$$

(For details, see Program Description.)

Newton's force equation may now be written in the form of equation B63 of reference B-1. The tooth forces

$$\bar{F}_{21} = -F_{12} \bar{n}_{12} \tag{B124}$$

and

$$\bar{F}_{f21} = \mu s_1 F_{12} \bar{n}_{N12} \quad (B125)$$

have the appropriate directions to account for friction. (The signum function s_1 is defined in reference B-1.)

Thus:

$$\begin{aligned} & -F_{21} \bar{n}_{12} + \mu s_1 F_{12} \bar{n}_{N12} + F_{x1} \bar{i} - \mu F_{y1} \bar{i} + F_{y1} \bar{j} + \mu F_{x1} \bar{j} \\ & = m_1 \{ -\omega^2 R_1 \bar{i} - (\omega + N_{31} \dot{\phi})^2 r_{c1} [\cos(\phi_{1c} + N_{31} \phi_T) \bar{i} + \sin(\phi_{1c} + N_{31} \phi_T) \bar{j}] \\ & + N_{31} \ddot{\phi} r_{c1} [-\sin(\phi_{1c} + N_{31} \phi_T) \bar{i} + \cos(\phi_{1c} + N_{31} \phi_T) \bar{j}] \} \end{aligned} \quad (B126)$$

where

$$\bar{n}_{12} = -\sin(\beta_1 - \theta_1) \bar{i} + \cos(\beta_1 - \theta_1) \bar{j} \quad (B127)$$

and

$$\bar{n}_{N12} = -\cos(\beta_1 - \theta_1) \bar{i} - \sin(\beta_1 - \theta_1) \bar{j} \quad (B128)$$

The moment equation must be written with respect to the accelerated point O_1 . The pivot reactions \bar{F}_{x1} and \bar{F}_{y1} are written such that the associated friction moments retard the counterclockwise rotation of the rotor. This leads to:

$$\begin{aligned} & -F_{12} R_{b1} + \mu s_1 a_1 F_{12} - \mu \rho_1 (\bar{F}_{x1} + \bar{F}_{y1}) \\ & = m_1 \omega^2 R_1 r_{c1} \sin(\phi_{1c} + N_{31} \phi_T) + I_1 N_{31} \ddot{\phi} \end{aligned} \quad (B129)$$

The forces \bar{F}_{x1} and \bar{F}_{y1} are obtained after the simultaneous solution of the following component expressions of equation B63 of reference B-1 for F_{x1} and F_{y1} :

$$\begin{aligned} & F_{12} \sin(\beta_1 - \theta_1) - \mu s_1 F_{12} \cos(\beta_1 - \theta_1) + F_{x1} - \mu F_{y1} \\ & = m_1 \{ -\omega^2 R_1 - (\omega + N_{31} \dot{\phi})^2 r_{c1} \cos(\phi_{1c} + N_{31} \phi_T) - N_{31} \ddot{\phi} r_{c1} \sin(\phi_{1c} + N_{31} \phi_T) \} \end{aligned} \quad (B130)$$

and

$$\begin{aligned} & -F_{12} \cos(\beta_1 - \theta_1) - \mu s_1 F_{12} \sin(\beta_1 - \theta_1) + F_{y1} + \mu F_{x1} \\ & = m_1 \{ -(\omega + N_{31} \dot{\phi})^2 r_{c1} \sin(\phi_{1c} + N_{31} \phi_T) + N_{31} \ddot{\phi} r_{c1} \cos(\phi_{1c} + N_{31} \phi_T) \} \end{aligned} \quad (B131)$$

Simultaneous solution of the above furnishes:

$$\tilde{F}_{x1} = F_{12}A_{23} \pm \omega^2 A_{24} \pm 2\frac{\omega^2}{|\omega|} N_{31} \dot{\phi} A_{25} \pm (N_{31} \dot{\phi})^2 A_{25} \pm N_{31} \ddot{\phi} A_{26} \quad (B132)$$

$$\tilde{F}_{y1} = F_{12}A_{27} \pm \omega^2 A_{28} \pm 2\frac{\omega^2}{|\omega|} N_{31} \dot{\phi} A_{29} \pm (N_{31} \dot{\phi})^2 A_{29} \pm N_{31} \ddot{\phi} A_{30} \quad (B133)$$

where

$$A_{23} = \left| \frac{(1 - \mu^2 s_1) \sin(\beta_1 - \theta_1) - \mu(1 + s_1) \cos(\beta_1 - \theta_1)}{1 + \mu^2} \right| \quad (B134)$$

$$A_{24} = \left| \frac{m_1 [R_1 + r_{c1} (\cos(\phi_{1c} + N_{31} \phi_T) + \mu \sin(\phi_{1c} + N_{31} \phi_T))] }{1 + \mu^2} \right| \quad (B135)$$

$$A_{25} = \left| \frac{m_1 r_{c1} [\cos(\phi_{1c} + N_{31} \phi_T) + \mu \sin(\phi_{1c} + N_{31} \phi_T)] }{1 + \mu^2} \right| \quad (B136)$$

$$A_{26} = \left| \frac{m_1 r_{c1} [\sin(\phi_{1c} + N_{31} \phi_T) - \mu \cos(\phi_{1c} + N_{31} \phi_T)] }{1 + \mu^2} \right| \quad (B137)$$

$$A_{27} = \left| \frac{\mu(1 + s_1) \sin(\beta_1 - \theta_1) + (1 - \mu^2 s_1) \cos(\beta_1 - \theta_1)}{1 + \mu^2} \right| \quad (B138)$$

$$A_{28} = \left| \frac{\mu m_1 R_1 + m_1 r_{c1} [\mu \cos(\phi_{1c} + N_{31} \phi_T) - \sin(\phi_{1c} + N_{31} \phi_T)] }{1 + \mu^2} \right| \quad (B139)$$

$$A_{29} = \left| \frac{m_1 r_{c1} [\mu \cos(\phi_{1c} + N_{31} \phi_T) - \sin(\phi_{1c} + N_{31} \phi_T)] }{1 + \mu^2} \right| \quad (B140)$$

$$A_{30} = \left| \frac{m_1 r_{c1} [\mu \sin(\phi_{1c} + N_{31} \phi_T) + \cos(\phi_{1c} + N_{31} \phi_T)] }{1 + \mu^2} \right| \quad (B141)$$

Equations B132 and B133 are now substituted into the moment equation B129.

$$\begin{aligned}
 & -F_{12} R_{b1} + \mu s_1 a_1 F_{12} - \mu \rho_1 [F_{12} (A_{23} + A_{27}) \pm \omega^2 (A_{24} + A_{28}) \\
 & \pm 2 \frac{\omega^2}{|\omega|} N_{31} \dot{\phi} (A_{25} + A_{29}) \pm (N_{31} \dot{\phi})^2 (A_{25} + A_{29}) \pm N_{31} \ddot{\phi} (A_{26} + A_{30})] \\
 & = m_1 \omega^2 R_{1c1} \sin(\phi_{1c} + N_{31} \phi_T) + I_1 N_{31} \ddot{\phi} \quad (B142)
 \end{aligned}$$

In order to have the pivot friction moment negative, the following terms on the left hand side of equation B142 must be negative:

$$\begin{aligned}
 & \mu \rho_1 F_{12} (A_{23} + A_{27}) \\
 & \mu \rho_1 \omega^2 (A_{24} + A_{28}) \\
 & \mu \rho_1 (N_{31} \dot{\phi})^2 (A_{25} + A_{29}) \\
 & 2 |\mu \rho_1| \frac{\omega^2}{|\omega|} N_{31} \dot{\phi} (A_{25} + A_{29}) \quad B-4
 \end{aligned}$$

The term $\mu \rho_1 N_{31} \ddot{\phi} (A_{26} + A_{30})$ is treated in the same manner as was shown in connection with equation A147 of reference B-1. (The discussion in appendix A of reference B-1 is also of interest for the determination of the effective moment of inertia I_{1R} .)

The above considerations give the moment equation the following form:

$$\begin{aligned}
 & -F_{12} [R_{b1} - \mu s_1 a_1 + \mu \rho_1 (A_{23} + A_{27})] - \omega^2 \mu \rho_1 (A_{24} + A_{28}) \\
 & - \frac{2 \mu \rho_1 \omega^2 N_{31} \dot{\phi}}{|\omega|} (A_{25} + A_{29}) - \mu \rho_1 (N_{31} \dot{\phi})^2 (A_{25} + A_{29}) \\
 & = m_1 \omega^2 R_{1c1} \sin(\phi_{1c} + N_{31} \phi_T) + [I_1 \pm \mu \rho_1 (A_{26} + A_{30})] N_{31} \ddot{\phi} \quad (B143)
 \end{aligned}$$

B-4 With $N_{31} \dot{\phi}$ = positive, must be absolute. See also discussion following equation A147 of reference B-1.

Finally, the above expression is solved for F_{12} , using the effective moment of inertia I_{1R} :

$$F_{12} = \frac{-A_{32} - A_{33}N_{31}\dot{\phi} - A_{34}(N_{31}\dot{\phi})^2 - A_{35}\sin(\phi_{1c} + N_{31}\phi_T) - I_{1R}N_{31}\ddot{\phi}}{A_{31}} \quad (B144)$$

where

$$A_{31} = R_{b1} - \mu s_1 a_1 + \mu \rho_1 (A_{23} + A_{27}) \quad (B145)$$

$$A_{32} = \mu \rho_1 \omega^2 (A_{24} + A_{28}) \quad (B146)$$

$$A_{33} = 2|\mu|\rho_1 \frac{\omega^2}{|\omega|} (A_{25} + A_{29}) \quad (B147)$$

$$A_{34} = \mu \rho_1 (A_{25} + A_{29}) \quad (B148)$$

$$A_{35} = m_1 R_{1c} r_{c1} \omega^2 \quad (B149)$$

$$I_{1R} = I_1 + |\mu|\rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have the same signs.} \quad (B150)$$

$$I_{1R} = I_1 - |\mu|\rho_1 (A_{26} + A_{30}), \text{ when } \dot{\phi} \text{ and } \ddot{\phi} \text{ have opposite signs.} \quad (B151)$$

Dynamics of Gear and Pinion Set No. 2 (applicable to both configurations with appropriate choice of s_6)

The free body diagram of gear and pinion set no. 2 is shown in figure B-10. Its force equation includes the D'Alembert force

$$T_2 = m_2 R_2 \omega^2 \quad (B152)$$

Thus,

$$\begin{aligned} -F_{23}\bar{n}_{23} - s_2 \mu F_{23}\bar{n}_{N23} + F_{12}\bar{n}_{12} - \mu s_1 F_{12}\bar{n}_{N12} + F_{x2}\bar{i} + \mu F_{y2}\bar{i} \\ + F_{y2}\bar{j} - \mu F_{x2}\bar{j} + T_2(\cos\gamma_2\bar{i} + \sin\gamma_2\bar{j}) = 0 \end{aligned} \quad (B153)$$

where

$$\bar{n}_{23} = \sin(\beta_2 + \theta_2)\bar{i} - \cos(\beta_2 + \theta_2)\bar{j} \quad (B154)$$

and

$$\bar{n}_{N23} = \cos(\beta_2 + \theta_2)\bar{i} + \sin(\beta_2 + \theta_2)\bar{j} \quad (B155)$$

The unit vectors \bar{n}_{12} and \bar{n}_{N12} were given by equations B127 and B128. Hence

$$\bar{F}_{32} = -F_{23} \bar{n}_{23} \quad (B156)$$

$$\bar{F}_{f32} = -s_2 \mu F_{23} \bar{n}_{N23} \quad (B157)$$

To write the moment equation, let

$$\ddot{\phi}_2 = N_{32} \ddot{\phi} \quad (B158)$$

where

$$N_{32} = -\frac{N_{P3}}{N_{G2}} \quad (B159)$$

Then,

$$\begin{aligned} F_{23} R_{b2} - \mu s_2 F_{23} a_2 - F_{12} r_{b2} + \mu s_1 F_{12} (d_1 - a_1) + \mu p_2 (\tilde{F}_{x2} + \tilde{F}_{y2}) \\ = I_2 N_{32} \ddot{\phi} \end{aligned} \quad (B160)$$

The conservative bearing forces \tilde{F}_{x2} and \tilde{F}_{y2} are obtained from the simultaneous solution of the following component equations of the force expression B153 for F_{x2} and F_{y2} :

$$\begin{aligned} -F_{23} \sin(\beta_2 + \theta_2) - F_{23} \mu s_2 \cos(\beta_2 + \theta_2) - F_{12} \sin(\beta_1 - \theta_1) \\ + \mu s_1 F_{12} \cos(\beta_1 - \theta_1) + F_{x2} + \mu F_{y2} + T_2 \cos \gamma_2 = 0 \end{aligned} \quad (B161)$$

and

$$\begin{aligned} F_{23} \cos(\beta_2 + \theta_2) - \mu s_2 F_{23} \sin(\beta_2 + \theta_2) + F_{12} \cos(\beta_1 - \theta_1) \\ + \mu s_1 F_{12} \sin(\beta_1 - \theta_1) + F_{y2} - \mu F_{x2} + T_2 \sin \gamma_2 = 0 \end{aligned} \quad (B162)$$

This leads to:

$$\tilde{F}_{x2} = F_{23} A_{36} + F_{12} A_{37} + T_2 A_{38} \quad (B163)$$

$$\tilde{F}_{y2} = F_{23}A_{39} + F_{12}A_{40} + T_2A_{41} \quad (B164)$$

(All signs are left positive in order to furnish positive friction moments in equation B160.) In the above:

$$A_{36} = \left| \frac{(1 - \mu^2 s_2) \sin(\beta_2 + \theta_2) + \mu(1 + s_2) \cos(\beta_2 + \theta_2)}{1 + \mu^2} \right| \quad (B165)$$

$$A_{37} = \left| \frac{(1 + \mu^2 s_1) \sin(\beta_1 - \theta_1) + \mu(1 - s_1) \cos(\beta_1 - \theta_1)}{1 + \mu^2} \right| \quad (B166)$$

$$A_{38} = \left| \frac{\cos \gamma_2 - \mu \sin \gamma_2}{1 + \mu^2} \right| \quad (B167)$$

$$A_{39} = \left| \frac{\mu(1 + s_2) \sin(\beta_2 + \theta_2) - (1 - \mu^2 s_2) \cos(\beta_2 + \theta_2)}{1 + \mu^2} \right| \quad (B168)$$

$$A_{40} = \left| \frac{\mu(1 - s_1) \sin(\beta_1 - \theta_1) - (1 + \mu^2 s_1) \cos(\beta_1 - \theta_1)}{1 + \mu^2} \right| \quad (B169)$$

$$A_{41} = \left| \frac{\mu \cos \gamma_2 + \sin \gamma_2}{1 + \mu^2} \right| \quad (B170)$$

Substitution of equations B163 and B164 into the moment equation B160 and subsequent solution for the contact force F_{23} give:

$$F_{23} = \frac{F_{12}A_{42} - T_2A_{43} + I_2 N_{32} \ddot{\phi}}{A_{44}} \quad (B171)$$

where

$$A_{42} = r_{b2} - \mu[s_1(d_1 - a_1) + \rho_2(A_{37} + A_{40})] \quad (B172)$$

$$A_{43} = \mu \rho_2 (A_{38} + A_{41}) \quad (B173)$$

$$A_{44} = R_{b2} - \mu[s_2 a_2 - \rho_2(A_{36} + A_{39})] \quad (B174)$$

Dynamics of Combined System in Coupled Motion (applicable to both configurations)

To obtain a single differential equation for the total system in coupled motion in terms of the escape wheel angle ϕ , an appropriate expression for the contact force F_{23} , which also contains the contribution of the rotor, must be substituted into either equation B100 or equation B119 for entrance or exit-coupled motion, respectively.

Thus, first substitute equation B144 for F_{12} into equation B171, which is the above expression for F_{23} :

$$F_{23} = \frac{1}{A_{44}} \left[\frac{-A_{42}A_{32}}{A_{31}} - T_2 A_{43} - \frac{A_{42}A_{33}}{A_{31}} N_{31} \dot{\phi} - \frac{A_{42}A_{34}}{A_{31}} N_{31}^2 \dot{\phi}^2 - \frac{A_{42}A_{35}}{A_{31}} \sin(\phi_{1c} + N_{31} \phi_T) + (I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}) \ddot{\phi} \right] \quad (B175)$$

Now, equation B175 is substituted into equation B100 or equation B119 and the final differential equation of coupled motion results:

$$A_{45} \ddot{\phi} + A_{46} \dot{\phi}^2 + A_{47} \dot{\phi} - A_{48} - A_{49} \sin(\phi_{1c} + N_{31} \phi_T) + A_{50} \sin(\gamma'_p - \psi - \psi_c) \quad (B176)$$

where^{B-5}

$$A_{45} = I_3 A_{18} + I_{PR} A_{17} U - \frac{A_{15} A_{18}}{A_{44}} (I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}) \quad (B177)$$

$$A_{46} = I_{PR} A_{17} V + A_{17} A_{21} U^2 + \frac{A_{15} A_{18} A_{34} A_{42}}{A_{31} A_{44}} N_{31}^2 \quad (B178)$$

$$A_{47} = 2 \frac{\omega^2}{|\omega|} A_{17} A_{20} U + \frac{A_{15} A_{18} A_{33} A_{42}}{A_{31} A_{44}} N_{31} \quad (B179)$$

^{B-5} The coefficients A_{45} to A_{50} are only valid for entrance contact; i.e., for equation B100. If exit-coupled motion is in operation, equation B119 is applicable and A_{17} becomes AA_{17} , and A_{18} becomes AA_{18} .

$$A_{48} = \frac{-A_{15}A_{18}A_{32}A_{42}}{A_{31}A_{44}} - \frac{A_{15}A_{18}A_{43}}{A_{44}} T_2 - A_{16}A_{18}T_3 - \omega^2 A_{17}A_{19} \quad (B180)$$

$$A_{49} = \frac{A_{15}A_{18}A_{35}A_{42}}{A_{31}A_{44}} \quad (B181)$$

$$A_{50} = m_p r_{cp} R_4 A_{17} \omega^2 \quad (B182)$$

Contact Force Equations for Coupled Motion (applicable to both configurations)

The contact force F_{23} is given by equation B175:

$$F_{23} = \frac{1}{A_{44}} \left[\frac{-A_{32}A_{42}}{A_{31}} - T_2 A_{43} - \frac{A_{33}A_{42}}{A_{31}} N_{31} \dot{\phi} - \frac{A_{42}A_{34}}{A_{31}} N_{31}^2 \dot{\phi}^2 - \frac{A_{35}A_{42}}{A_{31}} \sin(\phi_{1c} + N_{31} \phi_T) + (I_2 N_{32} - \frac{A_{42}}{A_{31}} I_{1R} N_{31}) \ddot{\phi} \right] \quad (B183)$$

The contact force F_{12} is found with the help of equation B171:

$$F_{12} = \frac{F_{23}A_{44} + T_2 A_{43} - I_2 N_{32} \ddot{\phi}}{A_{42}} \quad (B184)$$

The contact force P_n is given either by equation B96 or equation B117:

$$P_n = \frac{-I_3 \ddot{\phi} + F_{23}A_{15} - T_3 A_{16}}{A_{17}} \quad (B185)$$

Note that for exit-coupled motion; i.e., equation B117, the term A_{17} becomes AA_{17} . If this force is desired in terms of the pallet variable ψ , equation B76 or equation B107 must be used:

$$P_n = \frac{I_{PR} \ddot{\psi} + A_{21} \dot{\psi}^2 + 2 \frac{\omega^2}{|\omega|} A_{20} \dot{\psi} + \omega^2 A_{19} - m_p r_{cp} R_4 \omega^2 \sin(\gamma'_p - \psi - \psi_c)}{A_{18}} \quad (B186)$$

Again, note that for exit motion A_{18} becomes AA_{18} .

Differential Equations for Free Motion (applicable to both configurations)

Pallet Free Motion

By letting $P_n = 0$ in equation B186, the single free motion differential equation for the pallet, which is now independent of exit or entrance contact, is obtained.

$$A_{51}\ddot{\psi} + A_{21}\dot{\psi}^2 + A_{52}\dot{\psi} = -A_{53} + A_{54}\sin(\gamma_p' - \psi - \psi_c) \quad (B187)$$

where

$$A_{51} = I_{PR} \quad (B188)$$

$$A_{52} = 2 \frac{\omega^2}{|\omega|} A_{20} \quad (B189)$$

$$A_{53} = \omega^2 A_{19} \quad (B190)$$

$$A_{54} = \omega^2 m_p r_{cp} R_4 \quad (B191)$$

Escape Wheel - Gear Train - Rotor Free Motion

By setting $P_n = 0$ in equation B96 or equation B117, the common differential equation of the system without the pallet is obtained (again independent of entrance or exit contact). This leads to:

$$I_3\ddot{\phi} = A_{15}F_{23} - T_3A_{16} \quad (B192)$$

Equation B175 is then substituted into the above for F_{23} . The resulting differential equation is given by:

$$A_{55}\ddot{\phi} + A_{56}\dot{\phi}^2 + A_{57}\dot{\phi} = A_{58} - A_{59}\sin(\phi_{lc} + N_{31}\phi_T) \quad (B193)$$

where

$$A_{55} = I_3 - \frac{A_{15}}{A_{44}} N_{32}I_2 + \frac{A_{15}A_{42}}{A_{31}A_{44}} N_{31}I_{1R} \quad (B194)$$

$$A_{56} = \frac{A_{15}A_{34}A_{42}}{A_{31}A_{44}} N_{31}^2 \quad (B195)$$

$$A_{57} = \frac{A_{15}A_{33}A_{42}}{A_{31}A_{44}} N_{31} \quad (B196)$$

$$A_{58} = -A_{16}T_3 - \frac{A_{15}A_{43}}{A_{44}} T_2 - \frac{A_{15}A_{32}A_{42}}{A_{31}A_{44}} \quad (B197)$$

$$A_{59} = \frac{A_{15}A_{35}A_{42}}{A_{31}A_{44}} \quad (B198)$$

Contact Force Equations for Free Motion (the subscript F stands for free motion) (applicable to both configurations)

Equation B192 may be solved for the free motion contact force F_{F23} , once $\ddot{\phi}$ is known:

$$F_{F23} = \frac{I_3 \ddot{\phi} + T_3 A_{16}}{A_{15}} \quad (B199)$$

Equation B171, which was derived from the force and moment equations of gear and pinion set no. 2, may be modified to obtain the free motion contact force F_{F12} :

$$F_{F12} = \frac{F_{F23}A_{44} + T_2A_{43} - I_2N_{32}\ddot{\phi}}{A_{42}} \quad (B200)$$

It must be understood that in both equations B199 and B200 the angular acceleration of free motion $\ddot{\phi}$ as obtained from the solution of equation B193 is used.

Impact

While the following will show that the general form of the impact equation is the same for entrance and exit contact, it must be kept in mind that the expressions for the moment arms A'_1 , B'_1 , C'_1 and D'_1 depend on whether the angle α_{EN} or the angle α_{EX} is involved. (See equations D4, D5, D8, and D9 in appendix D.)

Entrance Impact

The general condition of entrance impact is illustrated in figure B-11. As in reference B-2, it is assumed that the only acting impulse on the pallet and the escape wheel is represented by the mutual normal impulse P_n between these mechanism components. Experience has shown that the frictional impulse μP may be disregarded. Under these circumstances, the angular impulse on the pallet becomes:

$$\bar{J}_p = D'_1 \bar{n}_t \times P_n \bar{n}_n = P_n D'_1 \bar{k} \quad (B201)$$

The angular impulse on the escape wheel is given by:

$$\bar{J}_3 = A'_1 \bar{n}_t \times (-P_n) \bar{n}_n = -P_n A'_1 \bar{k} \quad (B202)$$

If the above equations are made part of the usual angular momentum relationships, the components can be expressed as

$$I_p (\dot{\psi}_f - \dot{\psi}_i) = P_n D'_1 \quad (B203)$$

and

$$I_3 (\dot{\phi}_f - \dot{\phi}_i) = -P_n A'_1 \quad (B204)$$

where I_p and I_3 represent the polar mass moments of inertia of the pallet and the escape wheel, respectively. The subscript i indicates the angular velocities before impact while f indicates the same quantities after impact. When P_n is simultaneously eliminated from equations B203 and B204, the following expression results:

$$I_p A'_1 \dot{\psi}_f + I_3 D'_1 \dot{\phi}_f = I_p A'_1 \dot{\psi}_i + I_3 D'_1 \dot{\phi}_i \quad (B205)$$

Exit Impact

The conditions of exit impact are shown in figure B-12. With the same assumptions as in part a above, the expression for the angular impulse on the pallet becomes:

$$\bar{J}_p = D'_1 \bar{n}_t \times (-P_n) \bar{n}_n = -P_n D'_1 \bar{k} \quad (B206)$$

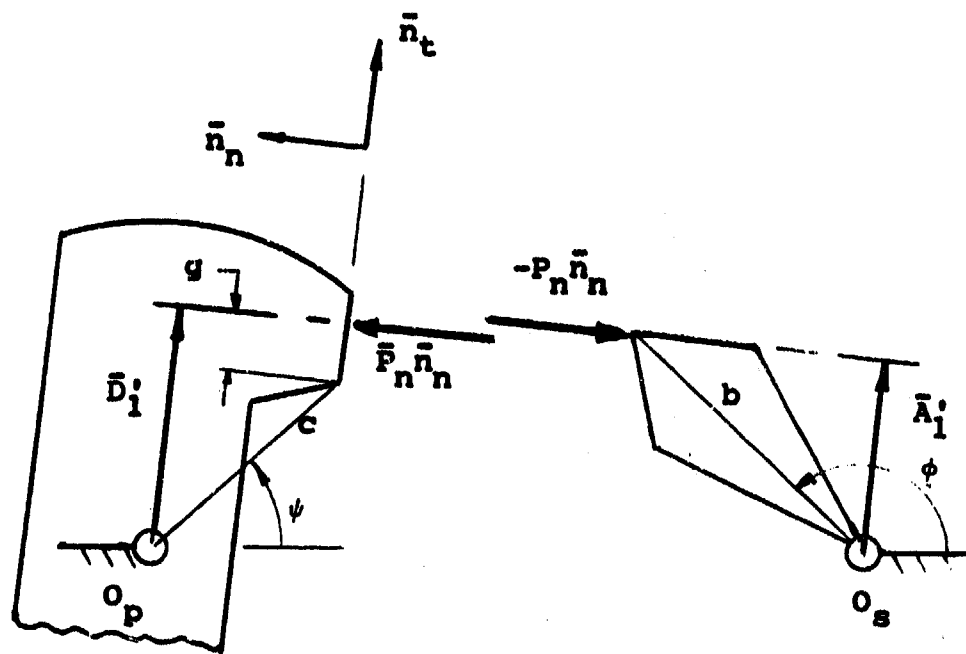


Figure B-11. Entrance impact

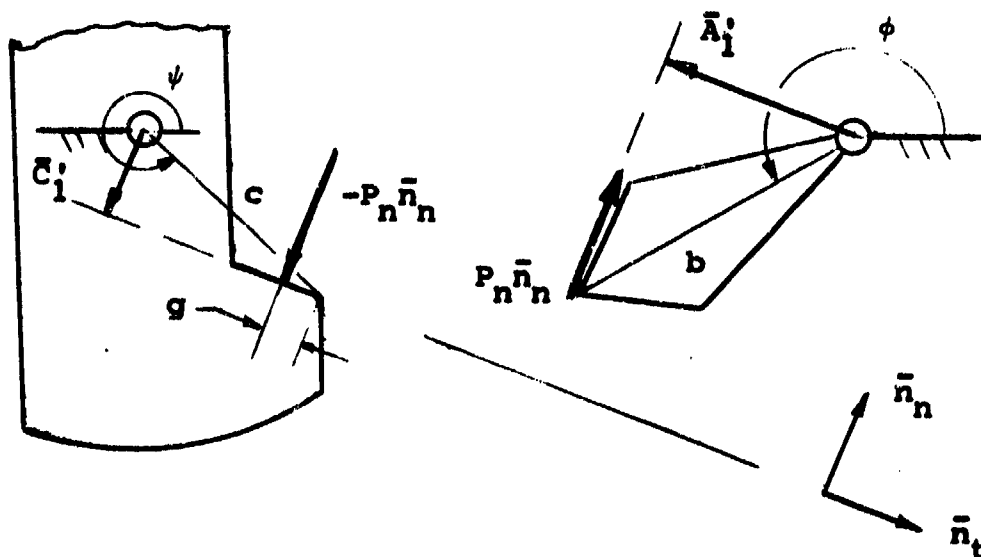


Figure B-12. Exit impact

The angular impulse on the escape wheel now becomes:

$$\bar{J}_3 = A'_1 \bar{n}_t \times (P_n) \bar{n}_n = P_n A'_1 \bar{k} \quad (B207)$$

Again, these expressions are used in the angular momentum formulations of both components, as follows:

$$I_p (\dot{\psi}_f - \dot{\psi}_i) = -P_n D'_1 \quad (B208)$$

and

$$I_3 (\dot{\phi}_f - \dot{\phi}_i) = P_n A'_1 \quad (B209)$$

When P_n is now simultaneously eliminated from equations B208 and B209, equation B205 results again. Thus, identical formulations may be used for entrance and exit contact.

Impact Equations for Escapement

In order to obtain expressions for the post impact angular velocities $\dot{\phi}_f$ and $\dot{\psi}_f$, the restitution equation

$$e_r = \frac{V_{TNf} - V_{SNf}}{V_{TNi} - V_{Sni}} \quad (B210)$$

must be solved simultaneously with equation B205. V_{TNi} and V_{Sni} are defined by equations D13 and D15 in appendix D. The velocities V_{TNf} and V_{SNf} represent the normal contact point velocities after impact. After appropriate substitutions, the simultaneous solution of these expressions furnishes:

$$\dot{\phi}_f = \frac{\dot{\phi}_i (I_3 D_1'^2 - e_r I_p A_1'^2) + \dot{\psi}_i I_p A_1' (1 + e_r)}{I_p A_1'^2 + I_3 D_1'^2} \quad (B211)$$

and

$$\dot{\psi}_f = \frac{\dot{\phi}_f A_1' - e_r (\dot{\psi}_i D_1' - \dot{\phi}_i A_1')}{D_1'} \quad (B212)$$

Changes in Impact Equation due to Presence of the Rotor and Gear and Pinion
No. 2

The presence of the rotor and gear and pinion no. 2 is accounted for by referring their moments of inertia to the escape wheel shaft. Thus, the total escape wheel moment of inertia is given by:

$$I_{STOT} = I_3 + I_2 N_{32}^2 + I_1 N_{31}^2 \quad (B213)$$

Equations B122 and B159 contain the above transmission ratios.

REFERENCES

- B-1. G. G. Lowen and F. R. Tepper, "Computer Simulations of Artillery S&A Mechanisms (Involute Gear Train and Pin Pallet Runaway Escapement)," Technical Report ARLCD-TR-81039, ARRADCOM, Dover, NJ, July 1982.
- B-2. G. G. Lowen and F. R. Tepper, "Dynamics of the Pin Pallet Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.
- B-3. G. G. Lowen and F. R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX C
KINEMATICS OF COUPLED MOTION

Nomenclature

The following derivations for the kinematics of coupled motion are applicable to both entrance and exit motion. It must be remembered that for entrance motion, according to figure C-1:

$$\alpha = \alpha_{en} \quad (C1)$$

and

$$g = g_{en} \quad (C2)$$

while for exit motion:

$$\alpha = \alpha_{ex} \quad (C3)$$

and

$$g = g_{ex} \quad (C4)$$

Further, from figure C-1

ϕ = Escape wheel angle, measured with respect to positive x' - axis.

ψ = Verge angle, measured with respect to positive x' - axis. For entrance condition, defined by line $O_p V$. For exit condition, defined by line $O_p W$ (measured ccw with respect to the positive x' - axis).

a = Distance between pivot points O_p and O_s

b = Escape wheel radius

c = For entrance condition, length $O_p V$. For exit condition, length $O_p W$ (usually identical).

Unit Vectors

Tangential and normal unit vectors, which are associated both with the entrance and the exit working surfaces, are shown in figure C-1. When expressed without distinction between these surfaces, they become:

$$\bar{n}_t = \cos(\psi + \alpha)\bar{i}' + \sin(\psi + \alpha)\bar{j}' \quad (C5)$$

and

$$\bar{n}_n = -\sin(\psi + \alpha)\bar{i}' + \cos(\psi + \alpha)\bar{j}' \quad (C6)$$

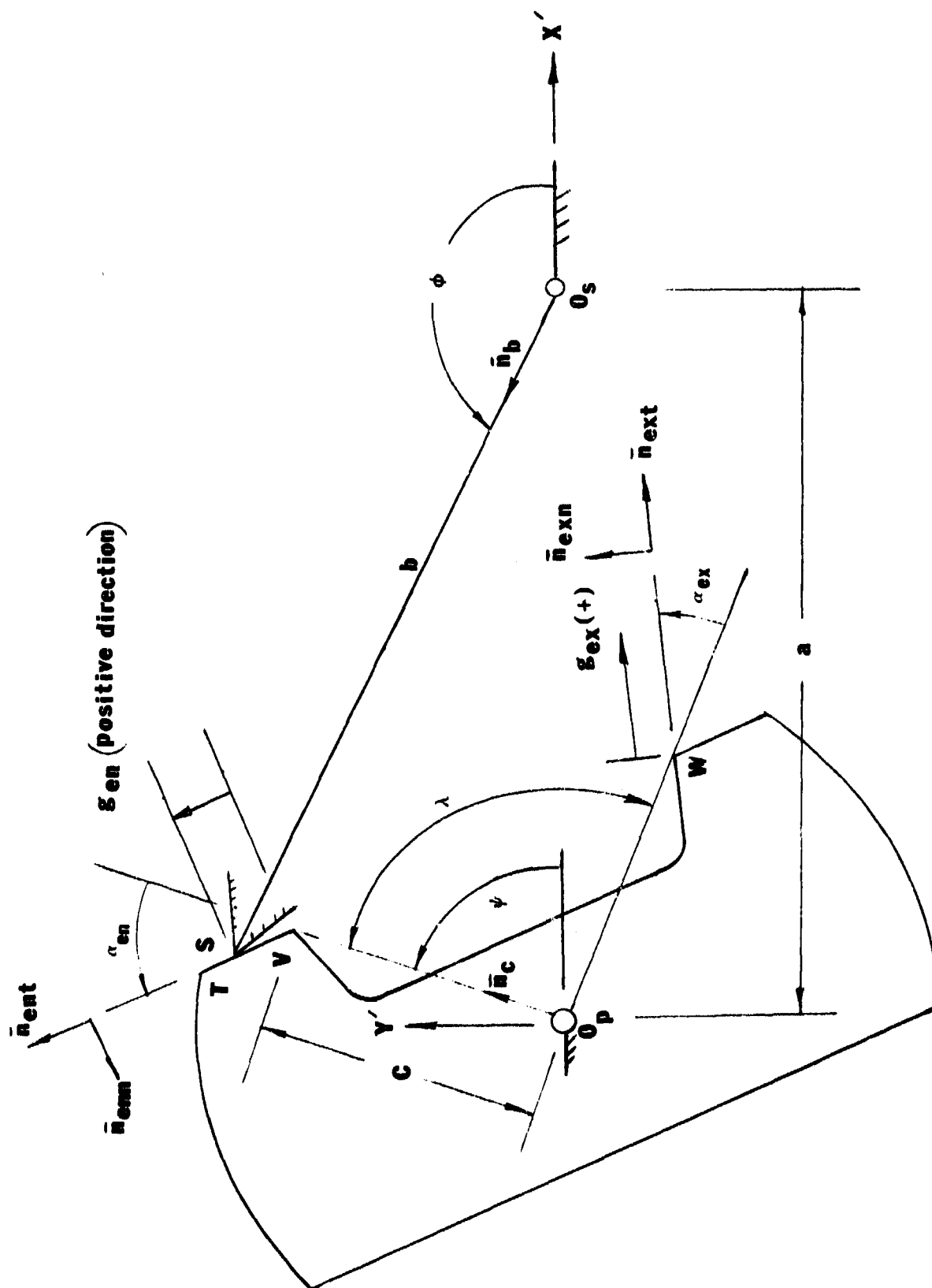


Figure C-1. Coupled motion nomenclature

$$\bar{n}_n = -\sin(\psi + \alpha)\bar{i}' + \cos(\psi + \alpha)\bar{j}' \quad (C6)$$

Further, the unit vectors in directions $O_s S$ and $O_p V$ (or $O_p W$), respectively, are given by

$$\bar{n}_b = \cos \phi \bar{i}' + \sin \phi \bar{j}' \quad (C7)$$

and

$$\bar{n}_c = \cos \psi \bar{i}' + \sin \psi \bar{j}' \quad (C8)$$

Loop Equation and Input-Output Relationship

The loop equation for coupled motion is given below. Contact point S is at the tip of the escape wheel tooth. The coincident point on the pallet is point T (fig C-1).

$$\overline{O_p V} + \overline{VT} + \overline{SO_s} + \overline{O_s O_p} = 0 \quad (C9)$$

Substitution of the appropriate dimensions and unit vectors into the above furnishes:

$$c\bar{n}_c + g\bar{n}_t - b\bar{n}_b - a\bar{i}' = 0 \quad (C10)$$

This becomes with the help of equations C5 to C8:

$$\begin{aligned} c(\cos\psi\bar{i}' + \sin\psi\bar{j}') + g(\cos(\psi + \alpha)\bar{i}' + \sin(\psi + \alpha)\bar{j}') \\ - b(\cos\phi\bar{i}' + \sin\phi\bar{j}') - a\bar{i}' = 0 \end{aligned} \quad (C11)$$

Appropriate ordering of equation C11 leads to component expressions which may be solved for g and ψ :

$$b\cos\phi + a - c\cos\psi - g\cos(\psi + \alpha) = 0 \quad (C12)$$

and

$$b\sin\phi - c\sin\psi - g\sin(\psi + \alpha) = 0 \quad (C13)$$

Both of these component equations may be solved for g . Thus,

$$g = \frac{b \cos \phi + a - c \cos \psi}{\cos(\psi + \alpha)} \quad (C14)$$

and

$$g = \frac{b \sin \phi - c \sin \psi}{\sin(\psi + \alpha)} \quad (C15)$$

g may be eliminated by setting equation C14 and C15 equal to each other. This leads to

$$(b \cos \phi + a - c \cos \psi) \sin(\psi + \alpha) = (b \sin \phi - c \sin \psi) \cos(\psi + \alpha) \quad (C16)$$

After expansion and rearrangement, a four-bar linkage type expression is obtained which may be solved for the angle ψ according to the method shown by R. Hartenberg and J. Denavit.*

$$A \sin \psi + B \cos \psi = C \quad (C17)$$

where

$$A = a \cos \alpha + b \cos(\phi - \alpha)$$

$$B = a \sin \alpha - b \sin(\phi - \alpha)$$

$$C = c \sin \alpha$$

The solution to equation C17 is of the form:

$$\psi = 2 \tan^{-1} \frac{A \pm \sqrt{A^2 + B^2 - C^2}}{B+C} \quad (C18)$$

Once the correct ψ has been obtained for a given α_{en} or α_{ex} , the associated g_{en} or g_{ex} may be found with the help of equation C14 or equation C15. For the given directions of the associated unit vectors g_{en} will be a positive quantity while g_{ex} will be a negative one.

* Kinematic Synthesis of Linkages, McGraw-Hill Publishing Co., New York, 1964.

Angular Velocity of Pallet

Implicit differentiation of equation C17 leads to the following expression for the angular velocity of the pallet when driven in coupled motion by the escape wheel:

$$\dot{\psi} = \dot{\phi} \frac{P}{Q} \quad (C19)$$

where

$\dot{\phi}$ = Angular velocity of the escape wheel

$$P = b \cos(\phi - \alpha - \psi) \quad (C20)$$

$$Q = a \cos(\psi + \alpha) + b \cos(\phi - \alpha - \psi) \quad (C21)$$

Relative Velocity of Contact Point S on the Escape Wheel with Respect to Contact Point T on the Pallet

With point S the tip of the escape wheel tooth and point T the coincident contact point of the pallet, the relative velocity $\bar{V}_{S/T}$ in the direction of the unit vector \bar{n}_t is found from (fig. C-1):

$$\bar{V}_{S/T} = [\bar{V}_{S/O_s} \cdot \bar{n}_t - \bar{V}_{T/O_p} \cdot \bar{n}_t] \bar{n}_t \quad (C22)$$

The velocity \bar{V}_{S/O_s} of point S with respect to the escape wheel pivot is obtained from

$$\bar{V}_{S/O_s} = \dot{\phi} \bar{k} \times b \bar{n}_b \quad (C23)$$

while \bar{V}_{T/O_p} , the velocity of point T with respect to the pallet pivot, is given by:

$$\bar{V}_{T/O_p} = \dot{\psi} \bar{k} \times (c \bar{n}_c + g \bar{n}_t) \quad (C24)$$

Substitution of equations C23 and C24, together with equations C5, C7, C8, into C22 leads, after the appropriate vector manipulations, to:

$$\bar{V}_{S/T} = -[\dot{\phi} b \sin(\phi - \psi - \alpha) + \dot{\psi} c \sin \alpha] \bar{n}_t \quad (C25)$$

It can be shown that the above expression also represents the vector $\dot{\bar{g}} = \dot{g} \bar{n}_t$, as obtained from the rate of change of the quantity \bar{g} , which was defined by equations C14 and C15.

Angular Acceleration of the Pallet

Differentiation of equation C19 with respect to time results in the following expression for the pallet angular acceleration:

$$\ddot{\psi} = U\ddot{\phi} + V\dot{\phi}^2 \quad (C26)$$

where, with equations C20 and C21

$$U = \frac{P}{Q} \quad (C27)$$

and

$$V = \frac{1}{Q^3} [aP^2 \sin(\psi + \alpha) - b(P - Q)^2 \sin(\phi - \alpha - \psi)] \quad (C28)$$

APPENDIX D

MOMENT ARMS AND NORMAL VELOCITIES OF CONTACT POINTS

Moment Arms

The following derivations for the moment arm vectors, which find use in both coupled motion and impact calculations, are valid for both entrance and exit conditions (figs. D-1 and D-2) as long as the appropriate angle α_{en} or α_{ex} is used. The variables ϕ and ψ must be available from the free motion computations.

The following loop for the determination of vectors \bar{A}_1 and \bar{B}_1 is shown by figure D-1:

$$A_1' \bar{n}_t + B_1' \bar{n}_n - b \bar{n}_b = 0 \quad (D1)$$

Substitution of the unit vectors given by equations C5 through C7 and subsequent separation of component expressions leads to the following two equations which may be solved for A_1' and B_1' :

$$A_1' \cos(\psi + \alpha) - B_1' \sin(\psi + \alpha) = b \cos \phi \quad (D2)$$

and

$$A_1' \sin(\psi + \alpha) + B_1' \cos(\psi + \alpha) = b \sin \phi \quad (D3)$$

Simultaneous solution of the above expressions for A_1' and B_1' leads to

$$\bar{A}_1' = b \cos(\phi - \psi - \alpha) \bar{n}_t \quad (D4)$$

and

$$\bar{B}_1' = b \sin(\phi - \psi - \alpha) \bar{n}_n \quad (D5)$$

Figure D-1 also serves for the determination of the vectors \bar{C}_1' and \bar{D}_1' . The loop equation

$$D_1' \bar{n}_t + C_1' \bar{n}_n - c \bar{n}_c - g \bar{n}_t = 0$$

furnishes, with the help of equations C5, C6, and C8 for the unit vectors, the following set of component expressions:

$$(D_1' - g) \cos(\psi + \alpha) - C_1' \sin(\psi + \alpha) = c \cos \psi \quad (D6)$$

and

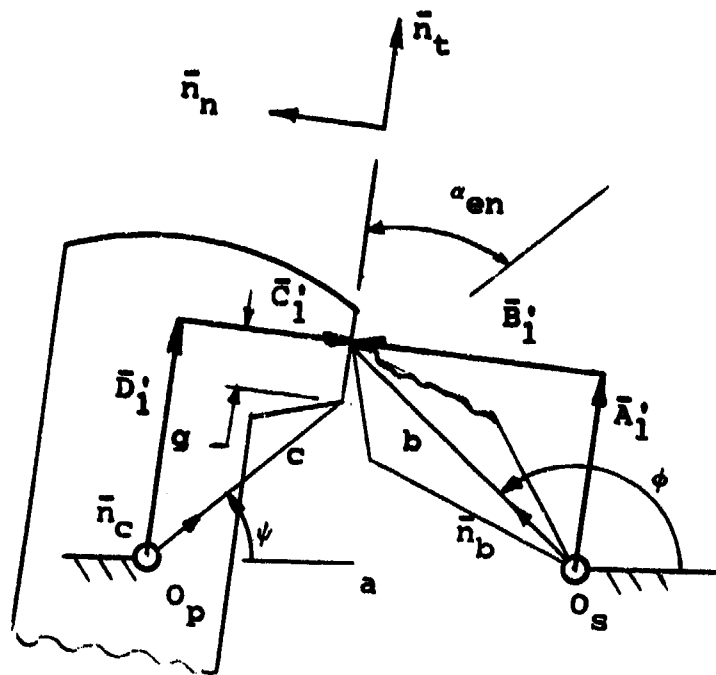


Figure D-1. Moment arms (entrance side)

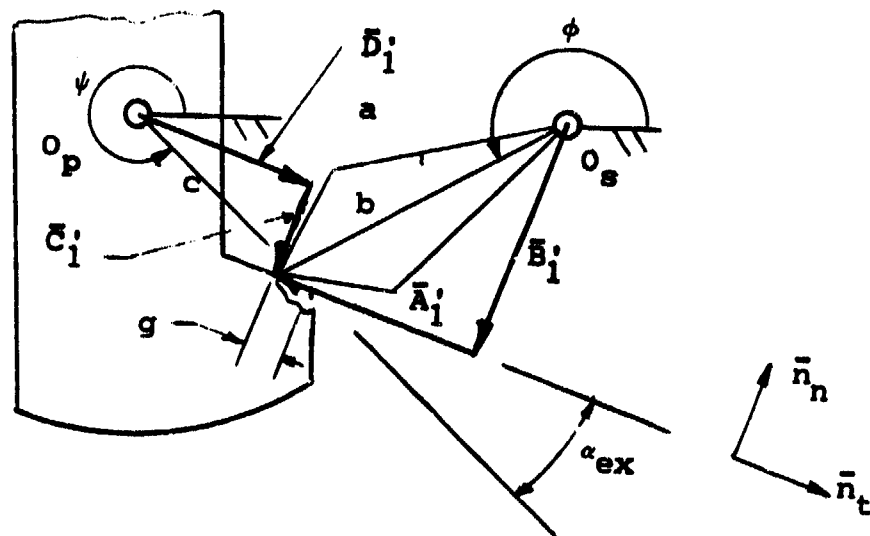


Figure D-2. Moment arms (exit side)

$$(D'_1 - g)\sin(\psi + \alpha) + C'_1\cos(\psi + \alpha) = c \sin \psi \quad (D7)$$

Simultaneous solution for C'_1 and D'_1 gives:

$$\bar{C}'_1 = -c\sin\alpha\bar{n}_n \quad (D8)$$

and

$$\bar{D}'_1 = (c\cos\alpha + g)\bar{n}_t \quad (D9)$$

Again, it must be remembered to substitute the appropriate entrance or exit values for α and g .

Normal Velocities of Contact Points Before and After Impact

The contact point S on the escape wheel and the contact point T on the pallet are shown in figure D-3. At the instant before impact, the respective escape wheel and pallet angular velocities are given by:

$$\bar{\dot{\phi}}_1 = \dot{\phi}_1 \bar{k}' \quad (D10)$$

and

$$\bar{\dot{\psi}}_1 = \dot{\psi}_1 \bar{k}' \quad (D11)$$

The associated velocity component \bar{v}_{SN1} of the escape wheel contact point S is obtained from:

$$\bar{v}_{SN1} = \bar{\dot{\phi}}_1 \times \bar{A}'_1 \quad (D12)$$

This velocity component is normal to the pallet face. This becomes, with the help of equations D10 and D4:

$$\bar{v}_{SN1} = b\dot{\phi}_1 \cos(\phi - \psi - \alpha)\bar{n}_n \quad (D13)$$

In a similar manner the velocity component \bar{v}_{TN1} of the pallet contact point T becomes:

$$\bar{v}_{TN1} = \bar{\dot{\psi}}_1 \times \bar{D}'_1 \quad (D14)$$

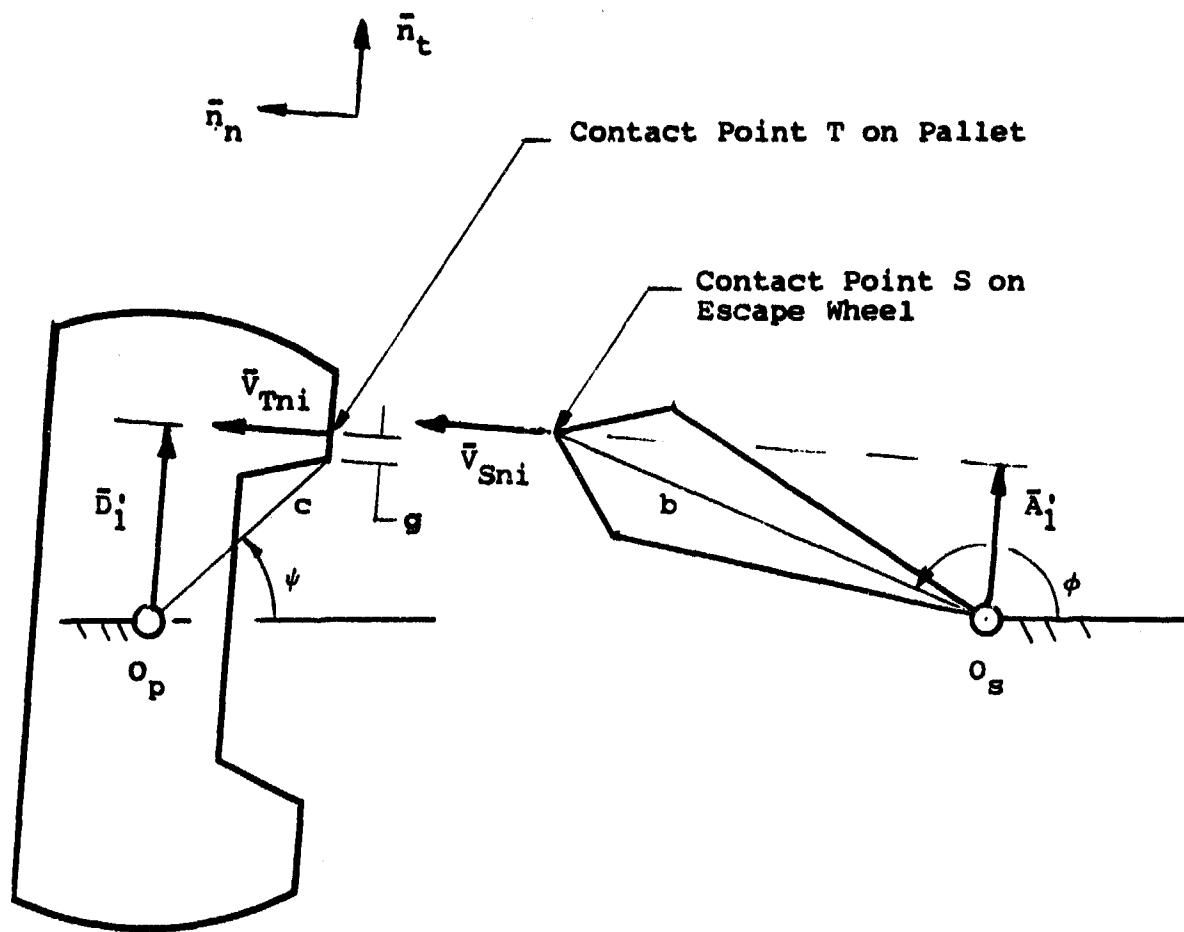


Figure D-3. Normal velocities of contact points S and T

This velocity component is also normal to the pallet face. Substitution of equations D9 and D11 into the above furnishes:

$$\bar{V}_{TN1} = \dot{\psi}_1 (c \cos \alpha + g) \bar{n}_n \quad (D15)$$

When equations D13 and D15 are adapted to the post-impact normal velocities \bar{V}_{SNf} and \bar{V}_{TNf} , the respective angular velocities $\dot{\phi}_f$ and $\dot{\psi}_f$ must be substituted (impact section of appendix B).

APPENDIX E

KINEMATICS OF FREE MOTION: CONTACT SENSING EQUATIONS

The contact sensing quantities f and g' for entrance and exit conditions are defined by figures E-1 and E-2, respectively. It is assumed that the angles ϕ and ψ are known at every instant of free motion. To determine the entrance side sensing quantities, the following loop equation is written:

$$\overline{OS} + \overline{ST} + \overline{TV} + \overline{VO_p} + \overline{O_p O_s} = 0 \quad (E1)$$

This becomes with the help of the appropriate unit vectors

$$b\bar{n}_b + f\bar{n}_n - g'\bar{n}_t - c\bar{n}_c + a\bar{i}' = 0 \quad (E2)$$

When a similar expression is written for the exit side (fig. E-2), the following relationship is obtained:

$$b\bar{n}_b - f\bar{n}_n + g'\bar{n}_t - c\bar{n}_c + a\bar{i}' = 0 \quad (E3)$$

The quantities f and g' have opposite signs in equations E2 and E3. If equation E2 is solved for f and g' with the help of the unit vectors of equations C5 to C8, then for the entrance side:

$$f = a\sin(\psi + \alpha) - b\sin(\phi - \psi - \alpha) - c\sin\alpha \quad (E4)$$

and

$$g' = a\cos(\psi + \alpha) + b\cos(\phi - \psi - \alpha) - c\cos\alpha \quad (E5)$$

The above expressions will yield positive numerical quantities. When the same expressions are used for the exit side (with the appropriate angle α^{ex}), the resulting numerical quantities will be negative because of the aforementioned sign differences between equations E2 and E3.

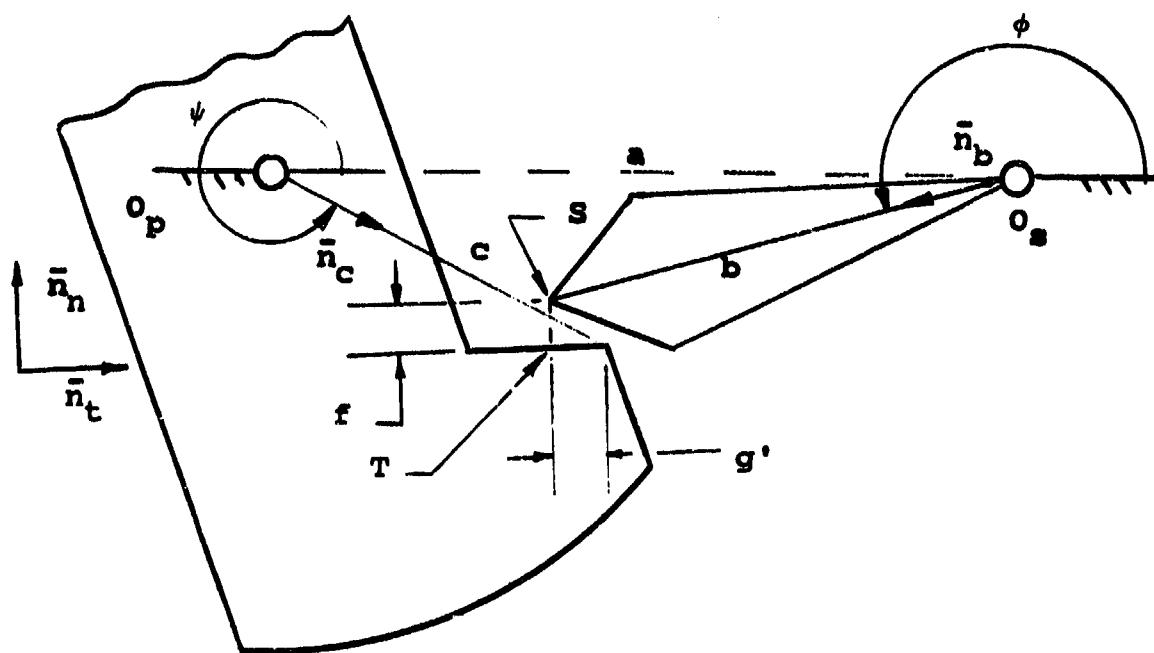


Figure E-2. Contact sensing on exit side (center distance not to scale)

APPENDIX F
GEOMETRY OF STRAIGHT-SIDED VERGE

Angles λ , α_{en} , and α_{ex}

The nomenclature of the indicated straight sided verge is defined in figure F-1. The angle λ is obtained as follows:

$$\lambda = 2 \tan^{-1} \frac{h}{2L'} \quad (F1)$$

With the above, and angle η , the angles α_{en} and α_{ex} become, respectively:

$$\alpha_{en} = \pi - \frac{\lambda}{2} \quad (F2)$$

$$\alpha_{ex} = \frac{\lambda}{2} - \eta \quad (F3)$$

The angle η is a basic design dimension.

Lengths of Working Surfaces

Figure F-2 is used to find the distance p_{en} ; i.e., the length of the straight portion of the entrance working surface, as well as the corresponding length p_{ex} of the exit working surface of the verge.

The length $p_{en} = LV$ is determined from the difference in lengths

$$p_{en} = y(L') - \frac{h}{2} \quad (F4)$$

where

$y(L')$ = the y-coordinate of the point of intersection of the circle $x^2 + y^2 = r^2$, and the straight line $x = L'$

Then:

$$L'^2 + y^2 = r^2$$

and

$$y = \sqrt{r^2 - L'^2}$$

Equation F4 becomes:

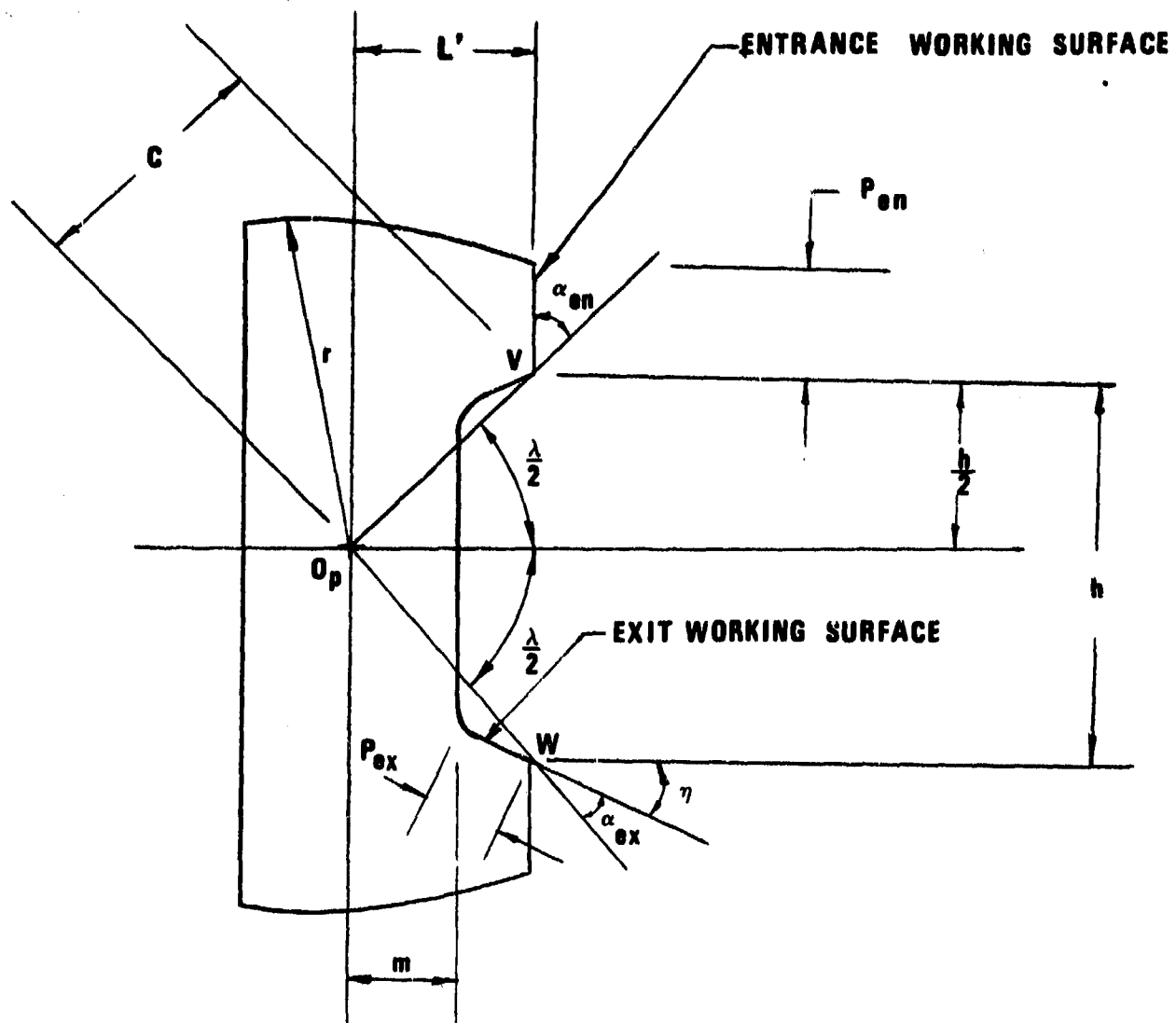


Figure F-1. Geometry of verge

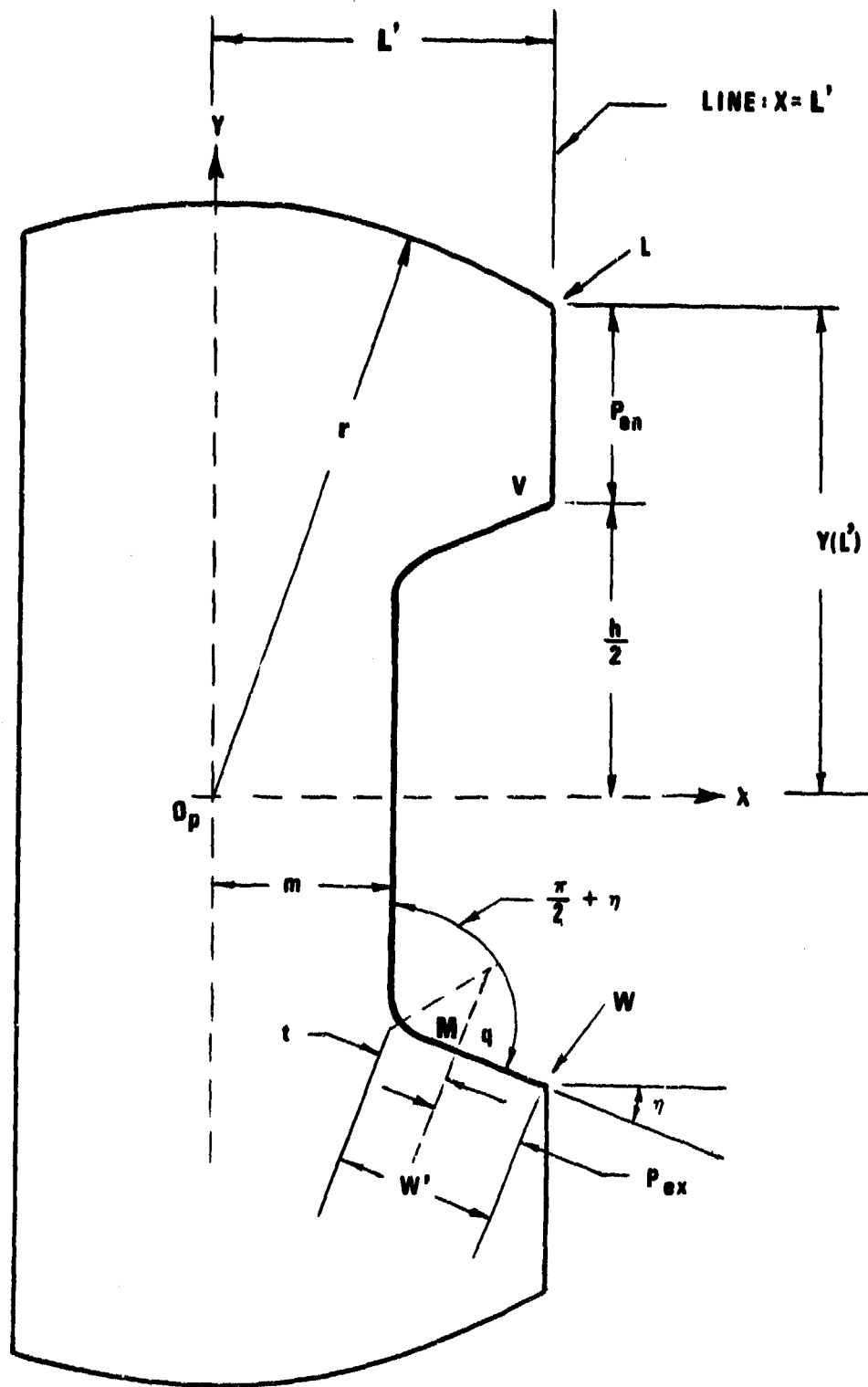


Figure F-2. Determination of p_{en} and p_{ex}

$$p_{en} = \sqrt{r^2 - L'^2} - \frac{h}{2} \quad (F5)$$

The length $p_{ex} = MW$ is obtained with the help of

$$p_{ex} = W' - t \quad (F6)$$

where point M represents the blend point between the fillet of radius q and the straight line of the exit working surface. The length W' is obtained from

$$W' = \frac{L' - m}{\cos \eta} \quad (F7)$$

while t is given by:

$$t = \frac{q}{\tan \left(\frac{\frac{\pi}{2} + \eta}{2} \right)} \quad (F8)$$

where $\frac{\pi}{2} + \eta$ is the angle spanned by the fillet. With the above, equation F6 becomes

$$p_{ex} = \frac{L' - m}{\cos \eta} - \frac{q}{\tan \left(\frac{\frac{\pi}{2} + \eta}{2} \right)} \quad (F9)$$

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